Improving dam and downstream community safety in Vietnam

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New dam development is underway in many developing countries but there is increasing recognition that existing dams are not being maintained adequately, and dam operators lack training and resources for their roles, particularly in emergencies. An initiative to address these concerns with a whole of river basin approach to risk reduction has been underway in Vietnam since 2012. Guidelines have been prepared for identifying the natural hazards affecting dams, determining the consequences of unplanned releases including dam failure, and improving coordination and disaster risk management. The evidence gathered using this methodology will be of great use to dam operators, officials and non-government agencies involved in dam management and disaster risk management at community level.

Vietnam has one of the largest dam systems in the world, comprising more than 7000 dams. Approximately 640 of these are classified as medium or large dams, and a large percentage of the Vietnamese population is potentially at risk from dam failure flooding, particularly if the operation of dams is inadequately considered.

In a collaboration between the Governments of Vietnam and New Zealand since 2012, a disaster risk reduction project to improve dam management and community safety throughout river basins has been developed by dam safety experts from both countries. Known as the 'Dam and Downstream Community Safety Initiative' (DDCSI), the project has developed a dam safety methodology (DSM) for dam owners and managers to identify and quantify the natural hazards and assess the risks associated with their dams, and develop options to mitigate these risks.

The methodology will be used to: identify and prioritize works and operational improvements needed to improve the safety of a dam; and, identify where disaster risk management can be improved for communities downstream of a dam. This will enable dam managers and owners to target specific improvements to manage existing reservoirs safely, or in the planning and design of future projects.

The methodology provides a choice of three levels of assessment, preliminary, intermediate or detailed, depending on the data available and downstream impact of the dam. For dams with greater levels of impact, the intermediate and detailed assessments include four steps, related to understanding natural hazards, potential dam failure modes, downstream hazard impacts and dam safety and disaster risk management. As well as identifying where structural and operational improvements can be made to a dam, the methodology provides information on the consequences of a flood release or dam failure event. Such information aids decision making for improved community warning systems, escape routes, land zoning and physical protection works for infrastructure, industry and communities.

The DDCSI methodology promotes a river basin approach, based on internationally recognized methods and has been published as a series of guidelines in English and Vietnamese. The approach can be used for a single dam or a cascade of dams in a river basin in any country, and across international borders. The methodology has been successfully tested on three dams with varying sizes and impacts in one of the Ca river tributary catchments in Nghe An province, Vietnam.

In a continuation of the collaboration between the Vietnamese and New Zealand Governments, it has been proposed for the DSM to be implemented between 2016 and 2020 in river basins with a large number of dams in two Provinces of Vietnam. The Ca river catchment, one of the largest river basin systems in the country, has been proposed. In these two provinces, large populations centred on the lowland plains are affected each year by flooding. There are six major irrigation and hydro dams in this river basin, along with a large number of small irrigation dams, all upstream of the fourth largest city in Vietnam. The most vulnerable dams, or dams with the greatest potential downstream impact, will be addressed first.

1. Background

Vietnam has more than 7000 dams (see Table 1). With the country's topography ranging from mountainous inland highlands to densely populated coastal plains, a large percentage of the Vietnamese population is at risk from dam failure flooding. Poorly considered operation of dams can lead to serious and unexpected flooding. Past dam failures have caused the loss of many lives, as well as substantial impacts to property and the environment.

Addressing and improving dam safety has become a priority for the Government of Vietnam. A national legal framework for dam safety in the country was first introduced in 2007, with Government Decree No. 72/2007/NĐ-CP. This was revised in 2013 to improve the definition of responsibilities and practices. Government approval is pending. However implementation of consistent dam safety across the country is challenging because of the limited resources and a lack of tools and procedures to prioritize dam safety works, particularly for small irrigation dams in rural areas [Dam, *et al*, 2011[1]; VNCOLD, 2011[2]].

This paper describes the recent collaboration between the Governments of Vietnam and New

Table 1: Summary of the dam network in Vietnam [World Bank, 2015]

Dam height	Reservoir volume	Number of irrigation dams	Number of hydropower dams
> 50 m	-	3	32
15 to 50 m	> 3 × 10^6 m^3	551	54
< 15 m	< 3 × 10^6 m^3	6648	201

Zealand to develop the methodology to provide a site-specific assessment to:

- identify and prioritize works needed to improve the safety of a dam; and,
- identify where disaster risk management could be improved for communities downstream of a dam.

The Dam Safety Methodology has been developed under the Dam and Downstream Community Safety Initiative (DDCSI) to meet many of the objectives of Decree 72/2007/NĐ-CP. It allows dam owners and engineers to identify and quantify the natural hazards to their dams, assess their impact and risks and develop options to mitigate the risks. A river basin approach has been taken to identify natural hazards that could impact dams, their vulnerabilities and the consequences of an unintended release from a dam. This assists in the prioritization of repairs and upgrades based on risk to the population and damage to economic assets in the river basin.

The Dam Safety Methodology (DSM) was developed for application to a single dam or a portfolio of dams in a river basin or within a province, district or commune. While this has been an initiative based in Vietnam, the methodology could be applied in any river basin and, with cooperation, could be applied across country borders. The DSM is applicable to the design of new dams or for safety evaluations of existing dams, and can be applied to all types and sizes of dams.

2. Dam safety and its connection to disaster risk management

2.1 Dam safety management

Dam safety practice refers to the safe planning, design, operation and management of dams and their reservoirs for all stages of the dam's lifecycle (Fig. 1). ICOLD Bulletin 154 [In press[3]] states: "the fundamental dam safety objective is to protect people, property and the environment from harmful effects of misoperation or failure of dams and reservoirs."

While modern dam design would be expected to take account of dam safety, older dams are often not designed to the same standards. Risks arise when operational procedures are not adequate, or are not followed. Care and maintenance is not always satisfactory, or is not adequately funded. To counteract these risks, dam safety should be applied throughout the dam's lifecycle.

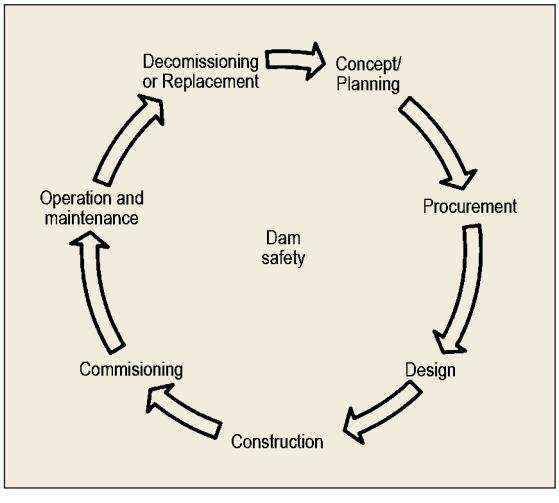

Fig. 1. Dam safety requirements over the lifecycle of a dam (adapted from ICOLD Bulletin 154 [In press[3]]).

Dam safety practice has evolved throughout the world since the 1970s, partly in response to a number of high profile incidents and disasters. The Teton dam failure in the USA in 1976 killed 11 people and led to total damages of US$ 2 billion. Following this disaster, dam safety legislation was introduced in the USA, and the US Bureau of Reclamation (USBR) introduced the Safety Evaluation of Existing Dams (SEED) programme and practices. Many features of the SEED programme became the basis for dam safety procedures around the world. Most importantly, these events led to the realization that regular maintenance and constant vigilance is required to ensure safe operation of a dam over many years.

More than 95 countries are members of the International Commission on Large Dams (ICOLD), which publishes agreed guidelines and standards of practice for the design, construction and operation of all types of dams. Worldwide there is a general effort to align national dam safety practice with the recommendations published by ICOLD. Many countries, including Vietnam, have laws (decrees) and regulations requiring dam owners to have dam safety programmes. The laws and regulations provide minimum requirements, which are usually well covered by national dam safety guidelines, commonly published by national dam safety organizations. Key differences from country to country tend to reflect their specific legislative and natural hazard context. The dam safety management systems published in well respected dam safety guidelines apply the principles promoted by ICOLD in its publications.

International dam safety bulletins and guidelines from a number of countries recommend that dam owners have a dam safety management system to provide a structured framework for the safe operation and management of their dams and reservoirs. The typical elements of such a system are summarized in Fig. 2.

The DSM (described in Section 3) provides information to make evidence-based decisions to rectify issues and improve dams or their operating systems and procedures. If no safety management system is in place for a dam, the DSM provides international practice and examples to develop and implement one.

2.2 Disaster risk management

Disaster risk management encompasses the planning and processes in place to manage the risk to communities from potential disaster events through social and physical measures. Potential dam-related events that can directly impact on society are uncontrolled reservoir releases (for example, spillway gates being opened without warning downstream communities) or a dam failure with release of the stored contents of the reservoir.

Social measures to manage dam-related disasters include: hazard mapping and analysis; vulnerability assessments; land-use management measures to avoid risks in new development; initiation of risk reduction initiatives; evacuation planning; sheltering of displaced people; emergency welfare support/relief; response management plans and infrastructure; response training exercises and drills; early warning systems; and, public notification. In the Vietnamese context, disaster risk management is required to be carried out at all organizations and at all levels of government down to the community level, extending to individual households (in accordance with Vietnamese Law No. 33/2013/QH13).

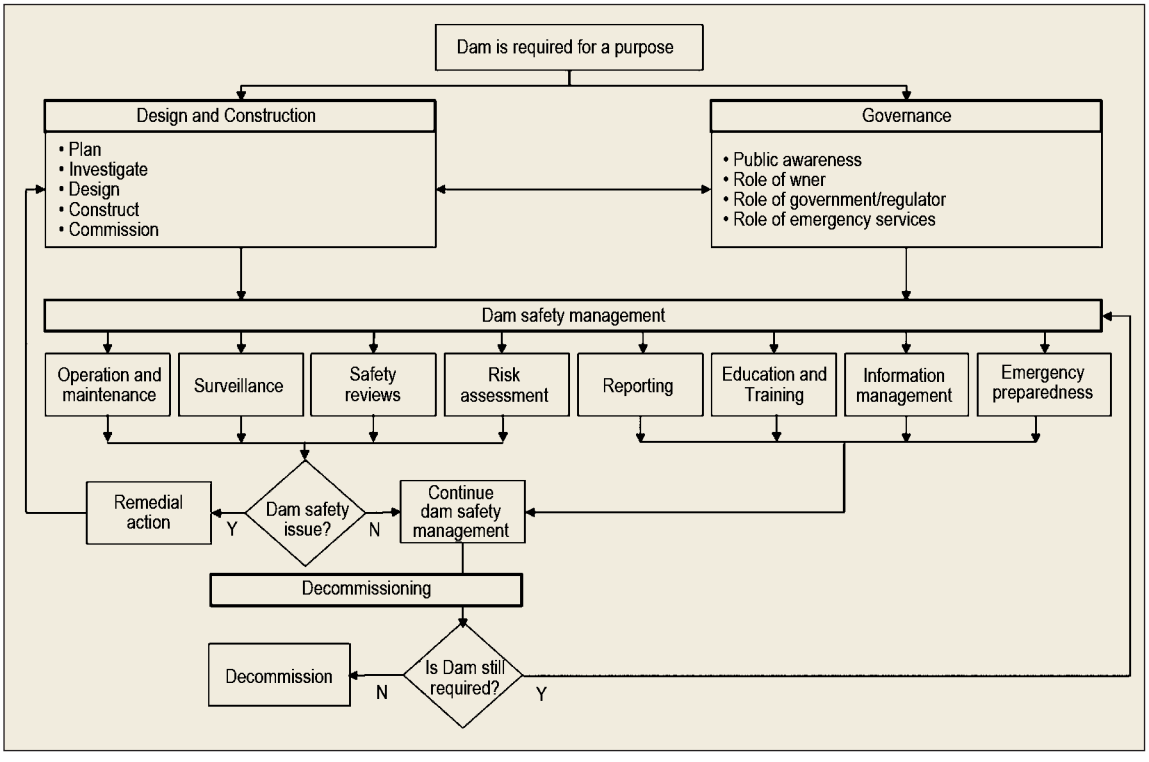

Fig. 2. Elements of a dam safety management system [adapted from ANCOLD, 2003[10]].

Physical measures to manage dam-related disasters include: flood protection embankments; strengthening buildings and infrastructure to mitigate the impact of physical hazards such as flood, storm and earthquake; and, moving communities or infrastructure away from high-risk areas, reforestation of burnt or cleared slip-prone land.

In Vietnam, disaster risk management is defined as comprising disaster prevention, response and mitigation (Vietnam Decision No. 1722007/QD-TTg). The national strategy emphasizes the need for timely response and effective recovery after events, which includes enhanced resilience in reconstruction recovery activities. Disaster risk management in the country is intended "to minimize the loss of human life and property, damage to natural resources and cultural heritage, and degradation of the environment, contributing significantly to ensure the country's sustainable development, national defence and security".

The DSM (described in Section 3) includes a provision to understand and analyse the current disaster risk management practices regarding a dam and whether there are gaps in capability or capacity and opportunities for improvements in planning and practice.

3. Development and testing of the DSM

3.1 The Dam and Downstream Community Safety Initiative (DDCSI)

Collaboration from 2012 to 2015 between the Vietnamese and New Zealand organizations listed below developed and tested a dam safety methodology under the auspices of the Ministry of Agriculture and Rural Development (MARD). Known as the Dam and Downstream Community Safety Initiative (DDCSI), the project aimed to deliver a nationally applicable process which would allow stakeholders to make well informed decisions to undertake structural and operational improvements to dam structures, as well as help to improve disaster risk management practices throughout the river basin. The organizations involved were:

- Thuyloi University, Hanoi, Vietnam;
- Vietnam National Committee on Large Dams;
- Vietnam Institute of Geophysics;
- GNS Science International Ltd of New Zealand; and,
- Damwatch Engineering Ltd of New Zealand

The methodology was developed based on internationally recognized methods and is published in a guideline that is available free of charge and published as an online download in English and Vietnamese from http://damsafety.thu.edu.vn [DDCSI, 2015[4]]. The trial of the Guideline produced a case study on three dams in Nghe An Province, Vietnam, which is also published. This is described in Section 3.3 below.

3.2 Overview of the DDCSI methodology

The framework of the methodology is shown in Fig. 3. The methodology is a sequential procedure that systematically assesses natural hazards (floods, earthquakes and landslides), their effect on the dam structure, hydraulic modelling of the unplanned release of water, or failure of the dam and mapping of the resulting flood. A thorough assessment of the consequences of a flood release will make it possible to document potential damage and identify the population at risk from a flood wave.

Table 2: Dam Safety Methodology levels of assessment

Assessment level	Description
Preliminary	Rapid assessment based on easily accessible data.
Intermediate	Assessment based on existing data and relatively routine analysis methods.
Detailed	Assessment based on site specific data, investigations and detailed analysis methods.

3.2.1 Level of assessment

The amount of effort required for dam safety assessment depends on site-related parameters. A more detailed assessment may be warranted for dams with larger reservoirs situated upstream of a relatively large population and where the consequences of dam failure would have significant downstream impact. Dams with smaller reservoirs which are upstream of sparsely populated areas may rely on less detailed methods of assessment. Based on this premise, three levels of detail of the DSM can be applied, as summarized in Table 2.

3.2.2 Preliminary assessment

The preliminary assessment provides a method to evaluate rapidly the potential downstream impact of a dam failure based on easily accessible information. The outputs from the preliminary assessment include:

- an approximate extent of inundation from a hypothetical dam breach flood; and,
- an estimate of the number of people who could potentially be impacted by the dam breach flood.

The preliminary level assessment can be used to:

- evaluate rapidly the potential downstream impact of a dam failure based on readily available information (for example, topographic maps, information on dam type, height and reservoir volume);
- evaluate a large number of dams in a province, district or commune to determine their relative downstream potential impacts (this information can be useful to prioritize investment and repair works to those dams with the highest potential downstream impacts); and,
- decide whether a dam requires further analysis at an intermediate or detailed level of assessment.

Once the preliminary assessment has been conducted, further assessment of dams with significant downstream hazard potential should be conducted using the intermediate and/or detailed level of assessment as appropriate.

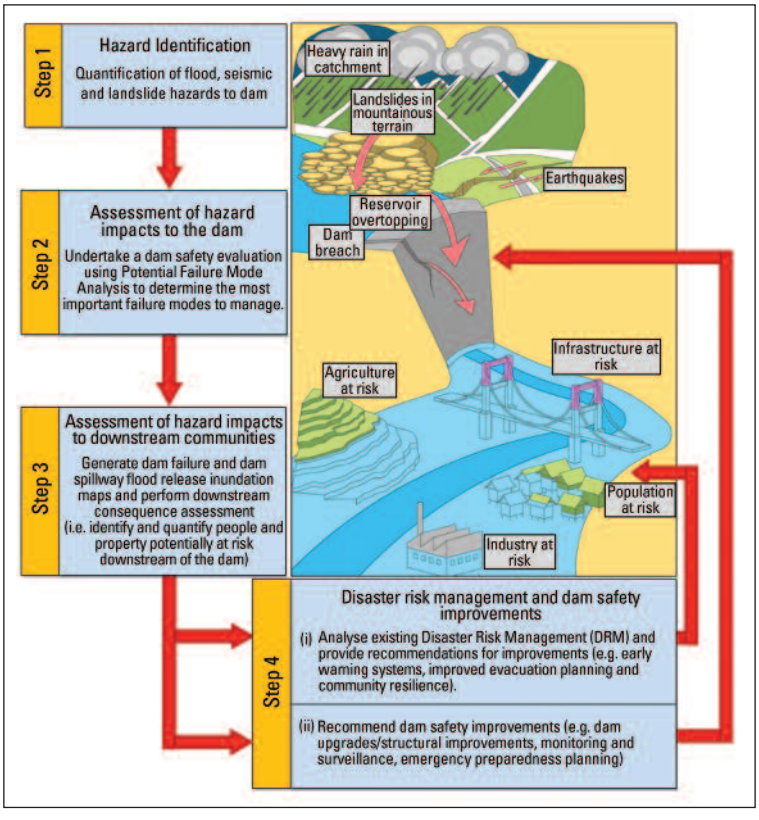

Fig. 3. Illustration of the Dam Safety Methodology (DSM).

3.2.3 Intermediate and detailed assessment

Fig. 4 provides an outline of the intermediate or detailed DSM. The intermediate and detailed assessments have the same overall methodology, but vary as a result of the amount and quality of data, resources and funding needed to conduct the assessment. Overviews of the four steps can be summarized as follows:

- *Step 1: 'Hazard Identification'* provides methods to quantify flood, seismic and landslide hazards to a dam using internationally recognized procedures (for example, ICOLD Bulletins 124 [2000[5]], 142 [2010[6]] and 148 [2012[7]]). Floods, earthquakes and landslides are recognized internationally as the primary natural hazards that can endanger the safety of dams. Quantifying these hazards in terms of magnitude and frequency of occurrence allows for informed decisions to be made on their impact on dam safety and methods to mitigate such hazards.
- *Step 2: 'Potential Failure Modes Assessment'* provides methods to carry out a dam safety evaluation. A potential failure mode is a mechanism or set of circumstances that could potentially result in the uncontrolled release of all or part of the contents of a reservoir. An understanding of potential dam failure modes, and providing avoidance, mitigation or monitoring to prevent or reduce the probability of a potential dam failure mode eventuating, is a cornerstone of effective dam safety management [NZSOLD, 2015[8]; USBR, 2012[9]].
- *Step 3: 'Hazard Impact on Downstream Communities'* provides recommended practice to generate dam failure and dam spillway flood inundation maps using computational hydraulic models. Geographic Information System (GIS)-based models are then used to estimate the impacts and losses from the flood events on people, property and agricultural land downstream. By providing information on the consequences of a potential dam failure or spillway release flood, dam owners can understand what design, construction

Table 3. General parameters for case study dams

Dam	District	Commune	Dam type	Year built	Catchment area (km^2)	Full supply level (m*)	Reservoir storage** (× 10^6 m^3)	Maximum dam height (m)	Structure class***
Khe Lau	Thái Hòa	Nghĩa Thuận	Earth	1977	4.0	+76.5	1.9	12	III
Sào	Nghĩa Đàn	Nghĩa Lam	Earth	2003	132	+75.7	51.42	31	II
Bản Mồng	Quỳ Hợp	Yên Hợp	Concrete with earth closure	Being built	2800	+76.4	235.5	44	I

* metres above Mean Sea Level ** at Full Supply Level *** according to Regulation QCVN 04 05:2012/BNNPTNT

and management actions can be applied to protect people, property and the environment.

• *Step 4: 'Dam Safety and Disaster Risk Management'* provides methods to make informed decisions to improve dam safety and disaster risk management practices. The general methodology to understand existing dam safety and disaster risk management systems involved:

(1) assembling and reviewing existing information on dam safety and disaster risk management, including a site inspection to the dam site if required;
(2) identifying any dam safety issues from surveillance and inspections, review of existing systems and procedures and potential failure modes assessment (see Step 2 above); and,
(3) developing improvements to any dam safety deficiencies or disaster risk management weaknesses identified.

Components of the intermediate and detailed assessments can be interchanged. For example, if frequent downstream flooding is a significant problem with the dam under consideration, then an overall assessment could be carried out at an intermediate level, but with detailed assessment of flood hazards and downstream flood impacts. Alternatively, if there is a known defect with the dam condition, then an overall assessment would be carried out at an intermediate level, but with detailed assessment for the potential failure modes and dam safety management.

3.3 Case study

Three large dams on a tributary catchment of the Ca river in Nghe An Province were selected to test the DDCSI methodology. The key parameters for the dams are listed in Table 3, and Fig. 5 plots the location of the dams. A preliminary assessment was carried out for Khe Lau reservoir, and an intermediate/detailed assessment for the Sao and Ban Mong reservoirs.

The results from the assessment are published in a case study report which is also available online in English and Vietnamese, and provides an example of an application of the assessment process outlined in the Guidelines. The case study provides a companion report to the Guidelines.

The case study successfully tested the DSM on three dams which are broadly representative of the types and sizes of dams throughout Vietnam. Feedback from stakeholders indicates that the DSM provides a robust, scalable, systems-based approach to understanding dam safety and disaster risk management issues for a dam or group of dams.

4. Application of the DSM to multiple dams in a large river basin

The successful development and testing of the DSM (as outlined in Section 3) led to an agreement between the New Zealand Government funder and the Ministry of Agriculture and Rural Development, Vietnam, that the project should be extended to an entire (major) river system. The Ca river basin (outlined in red in Fig. 5) has been proposed. The project, entitled the 'Vietnam - New Zealand Dam Safety Project' began in 2016 and will continue to 2020, in partnership between the Thuyloi University (formerly called the Water Resources University) Hanoi, the Vietnam National Committee on Large Dams, the Vietnam Institute of Geosciences and Mineral Resources, and GNS Science International Ltd and Damwatch Engineering Ltd, both of New Zealand.

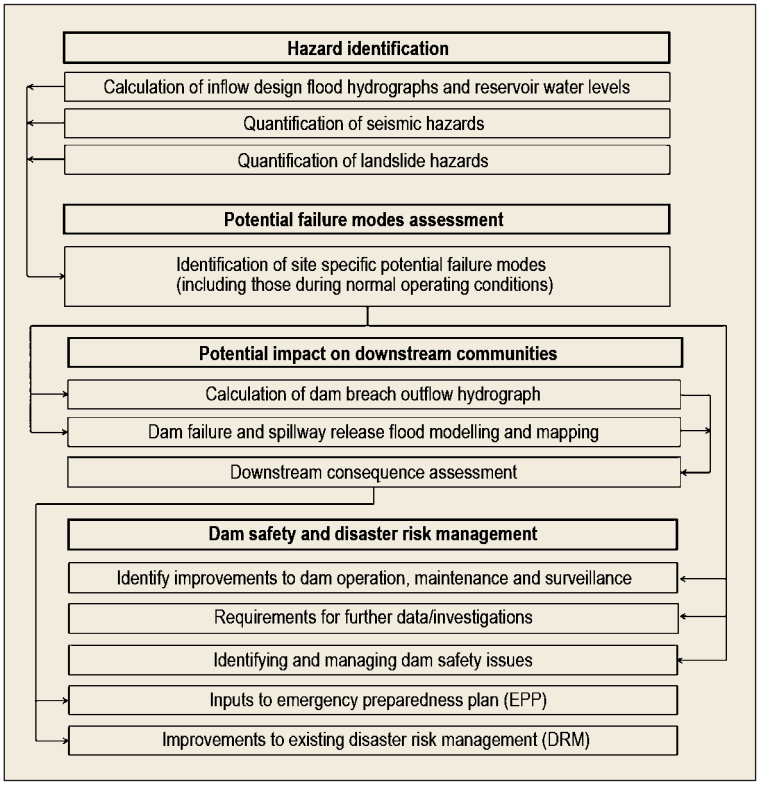

Fig. 4. Overview of the intermediate/ detailed Dam Safety Methodology.

The Ca river basin is in North Central Vietnam, and runs through both Nghe An province (with a population of 2.95 million) and Ha Tinh province (with a population of 1.23 million). The catchment is the fourth largest river basin in Vietnam, with a total area of approximately 27 000 km^2 of which 65 per cent is within Vietnamese territory. It is estimated that 978 dams are within the Ca river basin on Vietnamese territory, which vary in size and complexity (905 small, 58 medium and 15 large dams).

The range of dam stakeholders in the Ca river basin is both diverse and large in number, encompassing farmers, industrialists, dam operators/owners, local officials, Peoples' Committees, downstream commu-

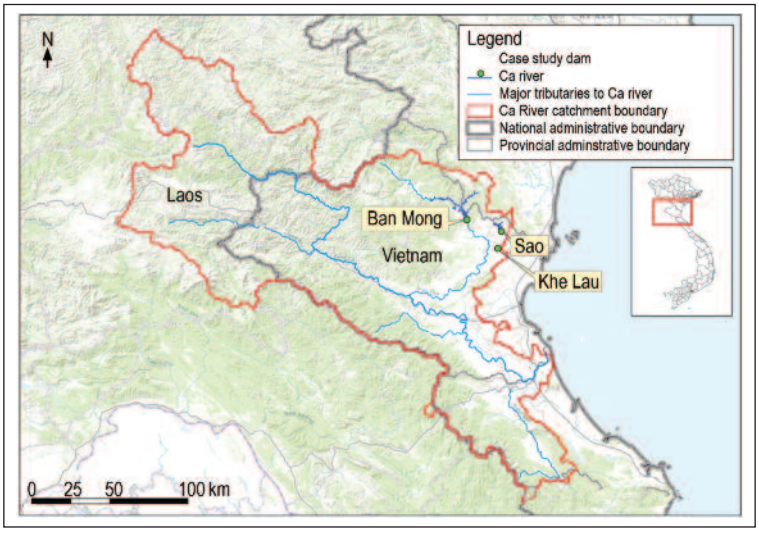

Fig. 5. Location of the case study dams and the Ca river basin.

Table 4: Objectives from project extension	
Short term outcomes	Increased stakeholder understanding of dam safety risks and disaster prevention practices.
	Refined prioritized list of dam upgrades for Ca river basin detailing specific areas for remediation.
Medium term outcomes	Greatest risk and impact dams in Ca river basin targeted for rehabilitation through other capital works projects (such as the World Bank-funded Vietnam Dam Rehabilitation and Safety Improvement Project and Government of Vietnam funding).
	High hazard dam owner/operators in Ca river basin effectively monitoring and managing dam safety risk.
	Improved communication with downstream communities on reservoir water releases.
	Relevant Vietnamese agencies undertaking more effective Land use planning in the Ca river basin.
	Next generation of water engineers, officials and dam owner/operators skilled in dam safety methodology.
Long term outcome	Roll out of DSM to other river basins.

nities and national and international non-governmental organizations working with them. Of these, three groups will be the most involved in the proposed project:

- dam owner/operators;
- officials responsible for disaster management, evacuation planning and land use planning (and local non-governmental organisation stakeholders who support that work);
- students of the Thuyloi University who will be the next generation of water resource managers in Vietnam.

The DSM will be applied progressively to major sub-catchments of the Ca river. The results for each sub-catchment will then be combined to represent the total basin and provide a consistent and evidence-based understanding of dam safety and disaster risk management issues across the Ca river catchment. This will allow dam stakeholders in the two provinces to identify dams needing rehabilitation and to prioritize each one in the assessment portfolio based on potential for greatest harm downstream.

A series of dam safety training courses for dam owner/operators, non-governmental organizations and local officials to build their capacity is an important part of the project, to support successful and sustained implementation of the DSM. These will be implemented across the entire Ca river basin during the project, and will also serve as a template for other river basins and provinces into the future. It is estimated that a total of 500 dam safety-related personnel can be trained across the two provinces.

Crucial to reducing the impact of flooding on downstream communities will be the work the project undertakes in identifying where and how dam owner/operators can best input potential flood release information into dam emergency preparedness plans for these downstream communities. NGOs who work with downstream communities around disaster risk management approaches will be key stakeholders for engagement by the project around this identification process and best use of flood release information.

A summary of the short-, medium- and long-term objectives of the project are outlined in Table 4.

5. Conclusions

Vietnam's large population of irrigation and hydropower dams have lacked a coordinated approach to dam safety at river basin level. Some dams are in poor condition, have poor operational practices, and low levels of coordination with dams in the same river system. These structural and operational deficiencies are exacerbated by the lack of accurate upstream forecasting of incoming floods. Downstream communities are largely unaware of upstream hazards and many lack effective disaster risk management plans and practices. Approaching dam safety management and disaster risk management on an integrated whole-of-river basin approach is new to Vietnam's management of its river systems.

A disaster risk reduction project known as the Dam and Downstream Community Safety Initiative (DDCSI) has been underway in Vietnam since 2012. The aim of the project is to improve dam management and community safety throughout a river basin. As described in this paper, the project has developed a dam safety methodology, based on internationally recognized methods, for dam owners and managers to identify and quantify the natural hazards and assess risks associated with their dams, and develop options to mitigate these risks. The methodology, with three levels of assessment according to the downstream impact of dam failure, includes provision to understand and analyse disaster risk management practices regarding a dam, and whether there are gaps in capability or capacity and opportunities for improvements in planning and practice. As well as identifying where structural and operational improvements can be made to a dam, the methodology provides information on the consequences of a flood release or dam failure event. This information aids decision making for improved community warning systems, escape routes, land zoning and physical protection works for infrastructure, industry and communities. The methodology also promotes a river basin approach, and has been published as a series of Guidelines in English and Vietnamese. The approach can be used for a single dam or a cascade of dams in a river basin in any country.

The Guidelines can be downloaded from the website: http://damsafety.tlu.edu.vn

With completion of successful testing of the DSM in a study of three dams in Nghe An province, Vietnam, approval has now been received to implement the same methodology to a large number of dams in two provinces of Vietnam in the Ca river catchment, one of the largest river basin systems in the country. In these two provinces, large populations centred on the low-land plains are affected each year by serious flooding. Dam flood releases may have increased the flood effects. Six major irrigation and hydropower dams are in this river basin, along with more than 800 small and medium height irrigation dams, all upstream of the fourth largest city in Vietnam.

The goal of the next phase, from 2016 to 2020, is to implement an evidence-based methodology for dam safety and disaster risk management using a whole river basin approach.

The DSM will be used to:

- identify and prioritize works and operational improvements needed to improve the safety of a dam; and,

• identify where disaster risk management can be improved for communities downstream of a dam. This will enable dam managers and owners to target specific improvements to manage safely existing reservoirs or the planning and design of future projects.

The evidence gathered by using this methodology will be of great use to the Peoples' Committees, officials and non-government agencies involved in disaster risk management at community level. The project will also collaborate closely with the World Bank funded Dam Rehabilitation and Safety Improvement Project (WB8), also underway in Vietnam. The projects are likely to complement each other, to provide effective risk reduction for the national dam infrastructure. ◊

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