Flood protection levees -from an existing portfolio of old structures to safe and reliable protection systems

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Flood protection levees – from an existing portfolio of old structures to safe and reliable protection systems

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ABSTRACT: In many countries, levees and flood defences raise (or have raised until recently) different issues associated to their ageing and often too to a lack of proper management during long periods of time. This leads to uncertain safety and performance, and sometimes catastrophic consequences. In this paper, based on an international confrontation of experience and lessons learned, we present the most important of these issues and a framework to better organize the management of these structures: identification of existing portfolios of structures, organizing them into consistent systems, the need for a high-level policy, for a proper local management and for technical guidance.

RÉSUMÉ: Dans de nombreux pays, les digues et autres ouvrages de protection contre les inondations soulèvent (ou ont soulevé jusqu'à récemment) différents problèmes liés à leur vieillissement et souvent aussi à un manque de gestion appropriée pendant de longues périodes. Cela conduit à une sécurité et des performances incertaines, et parfois des conséquences catastrophiques. Dans cet article, basé sur une confrontation internationale de retours d'expérience, nous présentons les plus importants de ces problèmes et un cadre pour mieux organiser la gestion de ces ouvrages: le recensement des structures existantes, les organiser en systèmes cohérents, la nécessité d'une politique de haut niveau, d'une bonne gestion locale et d'un corpus technique de référence.

1 INTRODUCTION

There are many issues associated with levees and other types flood defences, as they can sometimes be overlooked, even forgotten, particularly in places that have not suffered from a major flood event in a long period of time. This can lead to ageing, deteriorated portfolios

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of structures that will have a poor performance when the next major flood event happens, eventually causing paradoxically more damage than the same natural flood without defences.

Levees and flood defences have an important role in mitigating flood risk. Floods can have important or even catastrophic consequences on human life, the economy, the environment and cultural heritage, while an efficient flood protection system will be able to avoid all damage up to a certain intensity of event and lower the consequence above this level. The performance of flood protection systems is gaining importance in our modern world, as there is more at stake in the protected areas, where development is constantly increasing, while the natural hazards are also increasing due to climate change.

Many countries have important portfolios of levees and flood defences. Often, these structures are old or even very old, they were built sequentially, raised, repaired. . ., sometimes built locally by riparian owners without the global view of a hydraulically consistent system. This has led to a number of issues including:

– heterogeneity in the structures
– a lack of information;
– reduction or loss of awareness of the existence of the levees over time;
– uncertain performance both in terms of protection level and in terms of mechanical resistance due to a lack of continuous and proper management and maintenance.

In the recent decades, in different countries, the importance of safe and performant levee systems has been recognised after a catastrophic flood event.

Based on the authors' experience in their respective countries and the information exchanged with members of the ICOLD Technical Committee on Levees (ICOLD TC LE) and the EUCOLD Working Group on Levees and Flood Defences (EUCOLD LFD WG), in this paper presents common denominators, examples and specific approaches on how to restore an existing portfolio of flood defences and to ensure its lasting efficiency. More detailed information about ICOLD TC LE member countries information on their own issues and approach can be found in (EUCOLD Working Group on Levees and Flood Defenses, 2018) and (CIGB ICOLD, 2023).

2 REDISCOVERING LEVEES

In many countries, a major flood or storm event leading to catastrophic consequences was needed for the community to rediscover levees at a local or national scale, see Table 1.

During the Rhone River floods of the winter 1993-1994, which were the first important ones since 1856, breaches in the levees caused the flooding of the Camargue delta island, almost entirely included in the territory of the City of Arles. When they were informed, the technical services of the City of Arles were deeply surprised as they were not aware of the existence of levees, although all of the Rhone River in Arles is surrounded by levees. This example illustrates the level of forgetfulness about the existence and usefulness of levees, even locally, when floods do not occur for a long time. At a larger scale, in countries where flood prone areas are not the most heavily populated areas national governments have often considered floods a local issue.

It is often difficult to obtain adequate funding over time, particularly for the management and maintenance of levees. Financing in most countries has been intermittent and often follows large flood events. There are generally two options that are used for taking action after a catastrophic flood event:

- A first option is to repair the levees, even sometimes by rebuilding them stronger and higher than before and let things go back to the way they were before, without initiating a long-term policy for efficient flood risk management. This option usually results in a slow deterioration of the structures and the potential for a failure and flooding during a subsequent flood event.
- The second option, that some countries have chosen following a major or catastrophic event is to initiate a long-term policy for an efficient flood risk management and the safety and performance of flood protection structures and systems. Examples of this option are

Table 1. Some recent catastrophic floods involving levees, from (Tourment, 2018).

Country	Event	Consequences
Belgium, England, Netherlands	1953 Storm Surge	> 2500 casualties
Germany	1962 North Sea storm	340 casualties
Switzerland	1987 summer floods	8 casualties 1.2 billion CHF damages
Czech Republic, Germany, Poland	1997 Oder and Morava floods	114 fatalities 3.8 billion euro damage
France	1999 Aude river	25 casualties
Central Europe	2002 Danube, Elbe, Vltava floods	21 casualties > 12 billion euro damages
France	Three floods in 2002 and 2003 downstream Rhone river	14 casualties 2 billion euro damages
USA	2005 Hurricane Katrina	1836 casualties 125 billion dollar damages
UK	Summer 2007 floods	13 fatalities 3 billion £ damages
Italy	2010 Veneto flood	3 casualties 0.5 billion euro damages
France	2010 Xynthia storm	59 casualties, 1-3 billion euro damages
Japan	2011 Tohuko Tsunami	10-20,000 casualties, nuclear accidents (incl. Fukushima), 360 billion dollar damages
Germany	2013 Elbe, Saale, Danube floods	7 casualties > 4 billion euro damage

the Netherlands after the 1953 storm, England after the 1998 Easter floods (Bye, P., Horner, M., 1998), the USA after the 2005 hurricane Katrina, or after a series of events, like France after the 1993-1994, 1999, 2002 and 2003 floods and the 2010 Xynthia storm. This option usually takes time, years, maybe decades, and different steps before the policy can be in place and its effects reached and sustained.

3 GENERIC ISSUES WITH LEVEES

Beyond specific issues with individual levees or levee systems, at a large scale of a regional, national, or federal portfolio, in the absence of high-level policy[1] measures to ensure long term safety and efficiency of flood protection structures and systems some generic issues can be identified, in terms of governance or in terms of technical guidelines.

3.1 *Governance and funding*

When there is no high-level policy measure for the management of levees, it is common that levees built in the past become "orphan levees", with no management structure. This results in unawareness of the existence of the levees, their function, not to mention their safety and performance. When, in the absence of a general framework for levee management, there is an actual management for some levees, it is often fragmented and inconsistent at the system scale. This can lead to the performance and safety being reduced to the lower of all segments of the levee system. What makes this worse is that ownership of the land the levees are built on is necessarily fragmented in long levee systems. In absence of a distinct attribution of

1. In this paper we call "high-level" measures the ones that are taken at a federal, national, regional or large catchment scale. We cannot be more specific given the variety of situations in the different countries.

responsibility to a levee management structure, the responsibility of the levee management, therefore, falls into the land owners who usually don't have the skills nor the financial ability to properly and consistently maintain the levees.

Although legislation or regulations regarding flood risk management may be in place, however, this is often non-existent for the levees and flood protection structures. A surprising example is the EU Flood Directive which does not explicitly cover levees in its framework related to flood risk management, not even mentioning them.

Finally, funding the management of flood protection structures in the long term is very difficult. In most countries, funding has been intermittent and often follows large flood events and is devoted to repairing or building defence infrastructure. Furthermore, it is often difficult to obtain adequate funding over time for the management and maintenance of levees in spite of the fact that both of these aspects are crucial for the effective protection when a rare event happens. Levees, and more generally flood protection structures like flood control dams, have a public interest and their management and operation are more likely to be funded by public organisations. Funding for these organisations is usually generated by taxation of the public and there is a risk that if the public organisation's main objective is not flood risk management, funding for levees will not be guaranteed in the long term.

3.2 *Lack of technical guidelines*

Until recently, no commonly agreed levee specific guidelines/guidance existed which could be used in all countries in the world. This differs significantly from large dams, which benefit from a large body of technical guidance documents written at the international level thanks to the work of ICOLD, the World Bank and other international organisations and institutions. The first international initiative to draft a technical document covering levee issues has been the International Levee Handbook (ILH), started in 2008 and published in 2013 (Ciria, 2013) (Tourment et al., 2017).

Nonetheless some countries, like the Netherlands since the 1990's, have published their own specific technical guidelines in English, but these had no international status. National technical guidance devoted to levees is generally scarce since there is generally little or no interest in the levee issues, apart from the occurrence of catastrophic flood events. This is evidenced by the Netherlands where guidelines started ahead of other countries, after the 1953 storm surge. France had a wake-up call after the Rhone floods of 1993-94, which led to Cemagref initiating a series of technical and scientific publications on levees issues, for example (Mériaux, P. Royet, P., Folton, C., 2007) first published in French in 2001, followed by other institutions.

4 HIGH LEVEL POLICY MEASURES

Flood risk management relies on many different complementary and consistent measures, that can be structural or non-structural. Dams and levees are clear examples of structural measures while non-structural measures and instruments include for example activities related to emergency management and raising risk awareness, as well as financial and regulatory instruments. Flood protection structures, when pre-sent, are essential to flood risk management, but it is paramount to complement and be consistent with the other measures for the efficiency of a flood risk management policy. Hence, development of a policy regarding flood protection structures is necessary, but needs to be done consistently with the other flood risk management policies.

4.1 *Inventories*

At the Country, State, or catchment scale, considering national legislation, the first necessary step is to gather data on the existing portfolio: the existing structures, their location, the protected areas and assets situated in these areas; if not already existing, the identification and mapping of flood prone areas (with different flood levels/probabilities) has to be undertaken in association with this "census" of levees. This information on the structures has to be

sufficient in details and precision to enable a high-level assessment of their nature, safety and performance in terms of flood risk reduction, but also to assess residual risk, based on a quick, first level analysis.

A balance between risk and resources has to be found, both at the local and at the high-levels of management. It is necessary, therefore, to complete the inventory in order to form a base for all future high level policy measures, as the extent of the portfolio of structures and their performance in risk reduction is required to inform policy decision making.

4.2 *Legislation and regulation*

4.2.1 *Governance*

Governance of protection systems has then to be clearly organised, in terms of roles, responsibilities and also funding, in relation to already existing generic or specific regulations. As examples of generic regulations, there are those regarding the general ownership and management frameworks, while specific ones can deal with flood risk, water management, environmental issues, etc.

One of the main goals of the governance policy framework has to be the definition of the tasks and responsibilities of the organisation (or organisations) in charge of levees management, in order to solve the issue of "orphan levees", and to clearly define what has to be done by this (or these) organisation(s). Ideally levee management has to be performed at the scale of a hydraulically consistent levee system, or when not possible it has at least to be organised so that a form of coordination is organised at this scale. There are two main options to assign the responsibility of levees as follows:

- using dedicated organisations like in The Netherlands, where "WaterBoards" (regional water authorities) were created to tackle both flood risk and water management,
- by adding tasks to existing organizations like in France with groups of municipalities.

In both these options, the related legal frameworks are extensive covering both the organisations and the tasks separately (Flood Defences act 1996, NL and GEMAPI, 2014, France).

The second and equally important goal of the governance policy is to set up a sustainable funding mechanism for the organisation(s) responsible for levee management so they can properly conduct their tasks. This funding mechanisms has to be reliable and guarantee the levee manager's permanent ability to maintain the levee safety and performance. Usually, a more or less local funding source is the right scale, as it allows spending and benefits to be linked.

The governance policy can also deal with the issue of funding for large construction works like the construction of new defences, improvement of existing ones or important repairs after a major event. As this is an occasional task it can be based on a different mechanism as the one for regular management, and can involve national/regional solidarity.

4.2.2 *Risk*

Levees can be associated in a regulation framework to (flood) risk in two different ways: either as a risk factor (potential failure) or as a mitigating factor (protection performance). Some regulations are orientated to one or the other. For instance, in France the first regulation on hydraulic structures (dams and levees) from 2007 was centred on the failure of the levees and the associated risk, while the more recent 2015 regulation provides more emphasis on the protection provided by levee systems and flood retention structures (Tourment, R. et al., 2020). The reality is that flood protection structures change the flood risk, hopefully reducing it significantly, but they do not eliminate risk. Regulation should acknowledge both aspects to properly deal with these risk aspects.

The purpose of a flood protection policy framework should be in terms of risk to acknowledge the flood risk then to assess it and to manage it so it is acceptable (or tolerable) for society, which are actually the purposes of risk management in general. Using structures like levees or dams as flood management tools make it necessary to assess the natural flood risk (without protection structures), the risk associated to the structures (both in terms of reduction but also in case of failure) and consequently the residual risk, combination of both natural risk and risk associated to the structure.

A question is raised on the issue of tolerable or acceptable flood risk. Different countries use different approaches on the way to determine this tolerable risk, either at a national level or at a local community level. Consequently, determining the performance of the levees in terms of protection level, or failure probability or residual risk also can be done at a high level or left to a local level.

In any case, a risk approach is now the generally accepted way to deal with the issues related to floods and flood protection and, therefore, has to be as clearly as possible integrated in the policy frameworks.

4.2.3 *Management tasks*

The policy framework has to define what basic management operations have to be done in terms of management, and if different organisations are designated to share these management tasks what each one has to perform.

The management of levees has the objective to ensure that the levees will be able to perform as required during the flood event, ensuring the defined protection and not aggravating the flooding of the protected area by a breach (structural failure) or by another type of (functional) failure. The management organisations are among the first ones in the chain of decision when an important change has to be made in the system.

Section 5 describes in more detail the roles related to local management.

4.2.4 *Control*

The high-level framework needs to be implemented to be actually efficient. To be sure that it is correctly applied the national/ regional/federal level may want to organize a control organisation in charge of checking the way local levee managers properly fulfil their responsibilities. It is important that this control level should be separate from the operational level, as some flood examples have shown that if a single organisation is not reporting to any other one it may fail to assume its tasks and responsibilities.

5 LOCAL MANAGEMENT

In order to ensure that the levees will be able to perform as required during the flood event, levee management organisations have to have a proper and constantly updated knowledge of their portfolio, but also ensure proper routine inspection and maintenance in normal times (routine), during floods and after floods. They also need to decide and define changes in the levee system, all by themselves or in association with other organisations (funding agencies, government, local authorities, ...), as in the end they will have to manage the updated system.

5.1 *Choosing the protection systems and structures to incorporate in a management portfolio*

In the situation of a "new" levee management structure "inheriting" existing structures when a high-level policy is put into place and creates the responsibility of levees management, as described in section 4.2.1, one of the first decisions to make is to decide which of these existing structures will be integrated in the levee management structure's portfolio. Maintaining and sometimes retrofitting or improving the different structures has a cost and has to be compared to the benefits in terms of damage reduction.

To inform this decision it is necessary to have a clear idea about the structures, their actual hydraulic role during a flood and their performance in terms of resistance to the different failure modes. Hydraulically consistent flood protection systems, associated with their related protected areas and stakes and protection level have to be assessed in this step. It may be decided to abandon certain systems and areas, but it is also necessary to ensure that abandoned structures will not cause harm in the event of a flood or structure failure. This may eventually lead to total or at least partial deconstruction of structures and levees.

5.2 *Regular (continuous) management*

In their permanent tasks, levee managers have to:

- clearly define their organisation, both internal and in relation with other organisations,
- conduct regular (routine) inspections,
- have regular safety assessments and risk analysis of the levees,
- as necessary, following a safety assessment, a risk analysis or a flood event, decide and conduct follow-up actions, like levee reinforcements or even system modifications,
- properly store and organise all knowledge about levees and all related information, both historical and new,
- prepare for emergency situations, in order to be able to conduct inspections before, during and after a flood and initiate emergency maintenance and operation,
- organise information of authorities in charge of early warning systems and evacuation plans, be able to rely on qualified help, in terms of specialised engineering and of construction.

Safety assessments and risk analyses are among the more powerful and useful tools to inform decision making. They allow managers to identify potential failure modes, the most probable failure locations and their consequences, as well as either structural or organisational remediation measures.

5.3 *Occasional improvements of existing structures and system*

Design, construction and management measures to restore or improve the safety and performance of flood protection systems have to be implemented at a system or structure scale. When determining what should be done, based on either a safety as-sessment and/or a risk analysis, it is important to decide who will carry out the work and whether it should be carried out at national, regional or local level. This may vary in a country over time according to the level of urgency and major repairs after a flood event are often taken up by national organisations e.g. NL 1953 (storm surge) and USA 2005 (Hurricane Katrina).

6 TECHNICAL GUIDANCE

At the technical level, there is a strong need for guidance, first because as stated earlier levee guidance has only begun to be developed recently, but also because science, techniques and practice are making continual progress. Guidance has become available in some countries at a national level, and to a lesser extent internationally. There is a strong need for national and international sharing of knowledge and good practices.

There is a danger that technical rules for engineering tasks, like design, assessment, risk analysis can be frameworks or detailed models to be followed faithfully, leaving less place to the engineer's mind or to innovations.

6.1 *Guidance providers*

Nationally and internationally, professional and scientific associations, learned socie-ties are among the main providers of recognised guidance. For levees and other hy-draulic structures, this includes ICOLD, ISSMGE, IAHR and their national chapters. Some research institutions are also providing guidance related information or useful basic science, either by themselves or by participation in collective research projects, like for instance the EU FP7 research project FloodProBE (http://floodprobe.eu).

The need for an international Community of Practice (CoP) on Flood Risk Management (FRM) and also one focused on levees has been recognised in the final workshop common to the FloodProBE and the ILH projects. The interest of a CoP involving all types of actors and the links between these types is shown in Figure 1. Development of valid and usable guidance needs to involve all these types of actors.

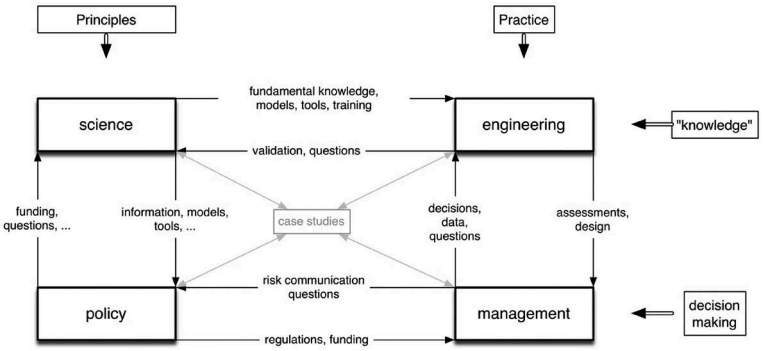

Figure 1. The FRM-CoP actors and interactions (© R. Tourment).

At the moment a permanent host organisation for a FRM-CoP has not been found, but ICOLD can now be seen as the international host for a levee CoP, as detailed in the next section.

6.2 *ICOLD and national dam committees*

Levees are now a clear part of the ICOLD activities. Since the creation of the working group on Levees and Flood Defences (https://lfd-eurcold.inrae.fr) of the European Club of ICOLD in 2015, the creation of the ICOLD Technical Committee on Levees in 2017, the fact that "Small Dams and Levees" were one of the four central topics in the Vienna ICOLD Congress in 2018 and the many activities related to levees in the Marseille ICOLD Congress in 2022 (see https://lfd-eurcold.inrae.fr/index.php/2022/07/20/levees-in-icold-and-highlights-of-levees-in-the-marseille-icold-congress/) there is no doubt levees are as much a natural part of ICOLD activities as dams. Over time, more and more National Committees have included levees in their scope. In the ICOLD newsletter issued for the 2022 Marseille congress, Michael Rogers, then President of ICOLD, has called for "*all ICOLD National Committees and Technical Committees to continue the embracement of levees into the technical approach and scope of their individual ICOLD organizations*".

Design and construction of new levees or retrofitting of existing ones can be adapted from dam guidance, but needs specific development. In the near future, the bulletins produced by the ICOLD TC on Levees (TC LE) will support this development of levee guidance, as well as, hopefully, the bulletins developed by other Technical Committees taking into account the similarities and differences identified by TC LE in its deliverables.

6.3 *Important issues needing guidance*

Among the many technical issues needing more scientific and practical guidance, new or development of existing ones, the following issues have been identified, while not being an exhaustive listing:

- risk issues: understanding risks, levee systems risk analysis methods, consequence assessment (Tourment, R. et al., 2016),
- failure modes, failure scenarios (Simm, J. et al., 2012) (Van M.A. et al., 2022),
- spillways or spillway sections on levees, allowing safe overtopping for resilient levee systems (Degoutte G., Tourment, R., 2021).

Research is obviously also needed in many scientific domains, mainly geomechanics and hydrology/hydraulics, but that may not only be directly related to levees. A more comprehensive an overview of data needs, research needs and guidance needs can be found in (EUCOLD Working Group on Levees and Flood Defenses, 2018).

7 CONCLUSION

Levee failures in recent decades leading to catastrophic inundations in many countries, in Europe and other parts of the world, have made the authorities and the citizens aware that existing structures, often old, sometimes forgotten as they are only occasionally loaded, have to be properly managed and maintained. On the other hand, many countries are still not aware of the possible hazard of orphan levees and still need to initiate a national policy for levee safety and performance, hopefully before a catastrophic event occurs. We hope that ICOLD involvement, international exchange of information and, humbly, this paper that is a call for action in all countries, will help promote better levees and levee management for a better world.

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