EUROPEAN AND US LEVEES AND FLOOD DEFENCES

Characteristics, Risks and Governance

DIGUES ET OUVRAGES DE PROTECTION CONTRE LES INONDATIONS D'EUROPE ET DES USA

Caractéristiques, Risques et Gouvernance

EUCOLD Working Group on Levees and Flood Defences

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European and US levees and flood defences
Characteristics, Risks and Governance

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European and US Levees and Flood Defences

Characteristics, Risks and Governance

1 July 2018

Elbe-Levee in the Woerlitz Park, Germany (Reinhard Pohl)

EUCOLD Working Group on Levees and Flood Defences

USSD Levees Committe

International Commission on Large Dams

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This document has been drafted with care but we cannot guarantee that it covers all aspects of the discussed topics.
One must pay attention to the fact that the report gives only a summary of levee-related information in each Country. It is impossible to explain all the details and the intricacies of the laws, standards, etc.

This document also refers to some legislation. Especially on this topic, the information, analyses and conclusions in this document have no legal force and must not be considered as substituting for legally-enforceable official regulations. They are intended for the use of experienced professionals who are responsible to judge their pertinence and applicability.

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European and US Levees and Flood Defences Report
Characteristics, Risks and Governance

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Summary

This report from the Working Group on Levees and Flood Defences of the European Club of ICOLD (EUCOLD) is published in preparation for the 2018 ICOLD Congress in Vienna; this European Levee Report also includes a contribution from the USA, from the Levees Comittee of the United States Society on Dams (USSD). The objective of the report is to provide an overview of flood protection works and its issues in different countries.
The situation of levees in the eleven countries who participated to the report is presented in a specific chapter, including facts and figures about levees and flood defences, flood risk issues, major flood events, regulation, governance, technical guidance, management practices and finally knowledge gaps. A final chapter presents an analysis and a tentative synthesis of the collected information.

The main outcomes of this report are the high importance of flood defences in these countries in terms of infrastructure portfolio and of flood risk management, and the lack of an central levee inventory in the majority of these countries.
Levees seem to be a relevant issue in many countries or at least for many regions across European Countries. Countries like England, France, Germany, Italy, The Netherlands, Poland, Spain, and others each have several thousand kilometers of levees and many more still have a significant amount of levees.
The majority of levees and flood protection structures are found along rivers but, especially in Western Europe, a significant fraction of levees and structures have been built along the coasts and estuaries.
Levees often have a long and complicated construction history, many of them have been heightened step by step after major flood events.
For the whole of Europe, both annual flood damage and Flood Risk Management (FRM) investments run into the billions of Euros (per year), while the protected value is over two trillion Euro.
Levee management governance and legislation strongly differ by country. There is no central levee database and, from many countries, only estimated data and incomplete information were available.

Résumé

Ce rapport du Groupe de travail sur les Digues et ouvrages de protection contre les inondations du Club européen de la CIGB (EUCOLD) est publié en préparation du Congrès de la CIGB 2018 à Vienne; ce rapport sur les digues, initialement européen, comprend également une contribution des États-Unis, du Comité sur les digues de l'United States Society on Dams (USSD). L'objectif du rapport est de fournir un aperçu des ouvrages de protection contre les inondations et des problématiques associées dans différents pays.
La situation des digues (ou levées) dans les onze pays ayant participé au rapport est présentée dans un chapitre spécifique : faits et chiffres sur les levées et les inondations, risque d'inondation, inondations majeures, réglementation, gouvernance, conseils techniques, pratiques de gestion et enfin lacunes en termes de connaissances. Un dernier chapitre présente une analyse et une tentative de synthèse des informations collectées.

Ce rapport démontre la grande importance des ouvrages de protection contre les inondations dans ces pays en termes de patrimoine d'infrastructures et de gestion des risques d'inondation, et l'absence d'un inventaire central des digues dans la majorité de ces pays.
Les digues semblent être une question d'importance dans de nombreux pays ou au moins pour de nombreuses régions à travers les pays européens. Des pays comme l'Angleterre, la France, l'Allemagne, l'Italie, les Pays-Bas, la Pologne, l'Espagne et d'autres ont chacun plusieurs milliers de kilomètres de digues et beaucoup d'autres en ont également un linéaire important.
La majorité des digues et structures de protection contre les inondations se trouvent le long des rivières, mais, en particulier en Europe de l'Ouest, une partie importante en a été construite le long des côtes et des estuaires.
Les levées ont souvent une histoire de construction longue et compliquée, beaucoup d'entre elles ont été réhaussées pas à pas après les inondations majeures.
Pour l'ensemble de l'Europe, les dommages annuels causés par les inondations et les investissements dans la gestion des risques liés aux inondations se chiffrent en milliards d'euros (par an), tandis que la valeur protégée dépasse les deux billions d'euros.
La législation en matière de gestion et de gouvernance des digues diffère fortement d'un pays à l'autre. Il n'y a pas de base de données centrale sur les digues et, dans de nombreux pays, seules des données estimées et des informations incomplètes étaient disponibles.

1 Introduction

Worldwide, 15% of the global population is expected to live in flood-prone areas by 2050, and some 90 million people were actually affected by coastal or river floods during the last three decades. Throughout Europe, it is estimated that several dozen million people are at risk from flooding, and at least 2000 billion Euro of economic value might be affected. In the period 1950-2005, over 45 major flood events were reported which either involved over 70 casualties or over 0,005% of the European GDP in damage (http://www.starflood.eu/faqs-2/). No wonder, the 2015 EUCOLD Manifesto on Dams and Reservoirs points at the relevance of floods and the role dams could play in flood protection and flood peak reduction (see also Report of the European ICOLD Club Working Group “Dams and Floods”: Dams and floods in Europe. Role of dams in flood mitigation, 2010 http://cnpgb.apambiente.pt/IcoldClub/jan2012/EWG%20FLOODS%20FINAL%20REPORT.pdf).
In addition, levees (also called dikes, dykes or flood embankments) and other flood protection structures including urban flood walls, (upstream) regulating and flood protection dams have a key role in reducing this risk. Numerous recent floods have demonstrated that this is not just an academic risk, but a risk that even today regularly results in major damage and even risk to life across Europe. Even in recent years (1989-2008), floods caused about 150 casualties per year across Europe, as well as 40% of all natural disaster damage (EUCOLD Manifesto on Dams and Reservoirs, 2015).
Besides demonstrating the relevance of levees, this report also aims to give a first indication of levee-related issues, so as to facilitate future comparisons with issues related to dams, especially embankment dams and small dams. Especially the latter is receiving increased attention within ICOLD.Their vast number and (in many cases) unknown state may imply a significant safety and flooding risk.
The main outcomes of this report are the high importance of flood defences in the countries who participated to this report and the lack of an central levee inventory in the majority of these countries. Levees indeed seem to be a relevant issue in many countries, or at least for many regions across European Countries. Countries like England, France, Germany, Italy, The Netherlands, Poland, Spain and others each have several thousand kilometres of levee, and many more still have a significant amount of levees.
The majority of levees and protection structures are found along rivers but, especially in Western Europe, a significant fraction of levees and structures has been built along the coasts and estuaries.
Levees often have a long and complicated construction history, often they have been heightened step by step after major flood events.
For the whole of Europe, annual flood damage runs into the billions of Euros, as can be derived from http://www.starflood.eu/faqs-2/ but also from the data given in this report. Annual Flood Risk Management investments also run into the billions of Euros (see http://www.crue-eranet.net/partner_area/documents/D2-1MainReport.pdf) . According to the data given in this report, the protected value behind levees is even is over two trillion Euro.
Governance, legislation and responsibilities strongly differ per country. This also implies that some countries had a relatively easy job in contributing to this report, and others a very difficult job. In any case, there seems to be no such thing as a central levee database. Also, levee failure databases are only selectively available on a national level. It is worth mentioning here the development of an International Levee Performance Database (ILPD) within the Dutch SAFElevee project (see http://leveefailures.tudelft.nl).
This report is the first report of the EUCOLD (European Club of ICOLD) Working Group on Levees and Flood Defences. It serves as an overall and approximate inventory of the levees and protection structures themselves, of the value they protect, of the residual risk including recent flood events, and of maintenance, governance and legislation issues. Further updates are expected in later years under the auspices of the ICOLD Technical Committee on Levees (LE TC).

Every country chapter has the same format where the following issues are discussed:

1. Facts and figures on levees and flood defences
2. Protected value, safety standards and flood risk
3. Recent major floods and (near-)failures of levees
4. Legislation and governance
    a. Legislation and governance – implementation EU Regulations
    b. Legislation and governance – National legislation
    c. Legislation and governance – Governance
5. Guidelines and good practices
6. Common practices during Levee Life Cycle
7. Critical knowledge and data gaps; critical research needs
8. Summary of key facts
9. References

After the country chapters, the main results and conclusions as well as recommendations are reported. The Questionnaire that was used to gather initial information and prepare a report template is included in Appendix A. The report template format itself (including the requested information) is reported in Appendix B.

2 Belgium

2.1 Facts and figures on Belgian levees and flood defences

Belgium consists of two regions, Flanders and Wallonia. The Flemish Region accounts for 45% of the territory of Belgium and two thirds of its population. Where Flanders is relatively flat, a major part of the Walloon Region can be considered hilly, the so-called Ardennes (Figure B-1). As a consequence, in Flanders (fields), land reclamation since the 11th century created fertile agricultural land protected from storms at the North Sea by dunes and levees. Moreover, river training works in Flanders resulted in navigable waterways with ship locks of limited head and long stretches of dikes. In Wallonia, water management is characterized by the presence of large dams and narrow valleys, even a ship lift as well as an inclined plane rather than long stretches of dikes.

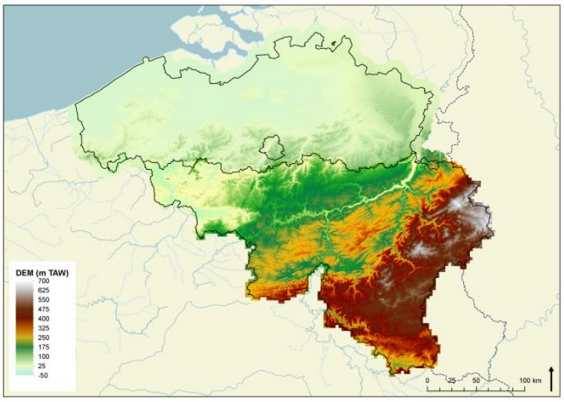

Figure B-1. Topographic map of Belgium (Source: GDI-Vlaanderen/Service public de Wallonie)

Within Belgium two river basin districts can be identified: the catchment of the Scheldt (Schelde) and the catchment of the Meuse (Maas). In terms of water management, a clear distinction exists between the navigable and non-navigable waterways. In addition, a coastline of almost 70 km needs to be protected from flooding (Figure B-2).

Belgian Coast

The coastline of Belgium is about 67 km long, including 10 municipalities (over 500.000 inhabitants), several public beach areas (18 million tourists/year), 2 commercial and 2 recreational ports as well as valuable nature areas (e.g. *Westhoek* and *Zwin*) (Figure B-3).

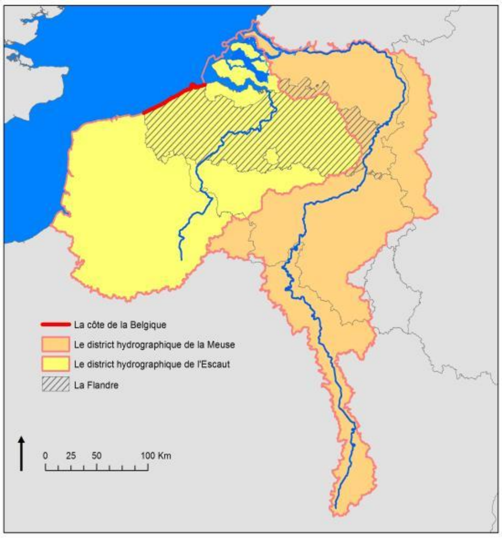

Figure B-2. Belgian coast and river basin districts of Scheldt and Meuse (Source: FHR)

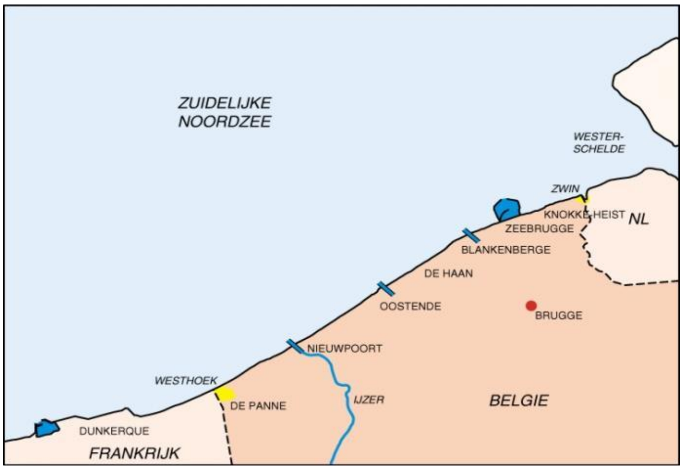

Figure B-3. General overview of the Belgian Coast (Source: Coastal Division)

The most important protection measure is the beach nourishment. Other measures are the construction of storm walls on sea walls (levees) and quay walls, broadening certain sea walls by the construction of a stilling wave basin, the construction of a storm surge barrier at the port of Nieuwport (Figure B-4).


Figure B-4. Flood defence measures along the Belgian Coast (Source: Coastal Division)

Scheldt

The mouth of the Scheldt-estuary is situated at the North Sea near the Dutch and Belgian coast. The most downstream part, called the Western Scheldt, belongs to the Netherlands. The more upstream tidal part is called the Sea Scheldt. Over 500 km of grass covered levees can be found along the Sea Scheldt and its tidal tributaries preventing uncontrolled flooding of the valley at high tide as well as during storm tides (Figure B-5). More upstream, the natural valleys still serve as the floodplain with submersible earthen embankments in place.

Figure B-5. Typical levee around a flood plain along the Sea Scheldt (Source: FHR)

Meuse

Coming from France, the Meuse runs through the Ardennes in Belgium. Here, the Meuse is canalized and regulated through the use of automated weirs. Large dams are located at some side branches. After a turn in the Netherlands, the Meuse acts as the border between Belgium and the Netherlands. At the left bank of the Meuse at the Belgian-Dutch border around a 60 km system of winter levees can be found.

Canals

Man-made canals and canalised rivers are numerous in Belgium. Although the majority have no embankments as such, parts are protected by levees resulting in quasi permanent loading conditions.

Only a limited number of dikes can be found along the smaller non-navigable rivers in Belgium. Recently, numerous (small) storage bassins together with a flood retention dam are installed in upstream regions.

2.2 Protected value, safety standards and flood risk

One of the objectives of the Belgian flood management is to seek to limit the damage. This can be achieved by using the approach 'risk = probability x vulnerability'. In the Flemish flood risk methodology the consequences of floods are assessed in terms of economic risk (expressed in euro/year) and human loss (expressed in casualties/year).

Belgian Coast

Protected value: 30 - 40 billion euros – Protected inhabitants: 150.000 - 200.000

The Coastal Safety Masterplan defines the tolerable wave overtopping discharge to be met in order to minimize the risks for a storm with 1000 year return period. The criteria can be summarized as follows:

- The mean wave overtopping discharge rate for a 1000-years storm over paved or armoured promenades or revetment seawalls is less than 1 l/s/m.
- Any erosion or damage to dunes or coastal structures caused by a 1000-years storm event must not result in damage to buildings behind the dune or coastal structure.

Updated Sigmaplan

Protected value: 100 - 150 billion euros – Protected inhabitants: 600.000 - 700.000

Due to changing physical circumstances and new insights into water management, an update of the Sigmaplan has recently been completed. The so-called updated Sigmaplan aims at satisfying safety and ecological needs along the tidal part of river Scheldt and tributaries in a sustainable way. Therefore different restoration techniques are elaborated which combine safety with estuarine restoration, e.g. dike strengthening together with more space for the river (e.g. managed realignment), flood control areas (FCA) with or without a controlled reduced tide (CRT) , non-tidal wetlands, etc. (Figures B-6 & B-7).

The foreseen protection levels range from 1/500 to 1/10000 years. Wave overtopping discharges up to 10 l/s/m are allowed provided a good status of the grass cover at the landside slope.

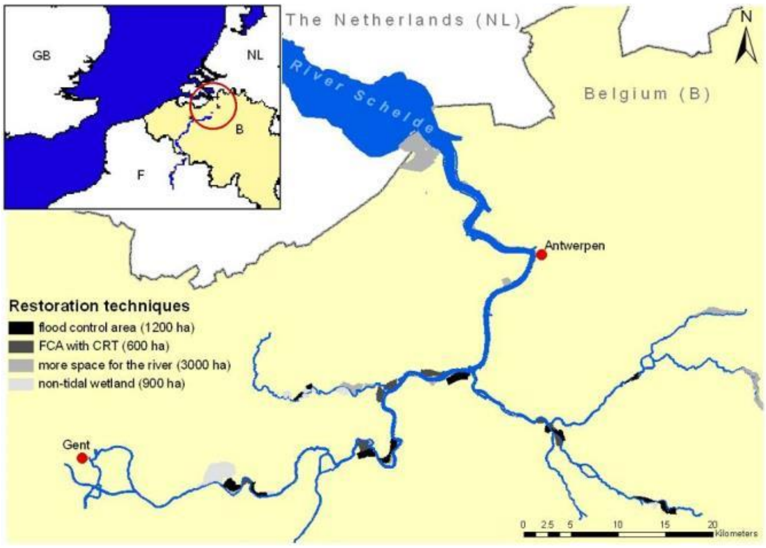

Figure B-6. General overview of the Updated Sigmaplan (tidal area) (Source: FHR)

Figure B-7. FCA Paardeweide in action in 2013 (Source: FHR)

Meuse

Protected value: 100 million euros – Protected inhabitants: 1.000

The safety plan for the Meuse on the border between Belgium and the Netherlands consists of a combination of room for the river and dike strengthening. Here, the foreseen protection level will be the 1/1250 year flood event.

2.3 Recent major floods and (near-)failures of levees

Major storm surges

The 1953 flood disaster led in Belgium to some near-failures and significant damages (Figure B-8).

Figure B-8. Near failure of the Belgium coastal defence at Knokke-Heist in 1953 (Source: Le Patriote Illustré) and, more recent, formation of cliffs in 2013 (Source: T. Verwaest)

The storm surge of 1976 resulted in serious damage and the loss of 6 human lives (Figure B-9). The safety plan for the tidal river Scheldt, called Sigmaplan (with the 'S' of the Scheldt), dates from 1977 and aimed at dike heightening and strengthening as well as the construction of flood control areas in combination with a storm surge barrier downstream of Antwerp. A stormy period in 1990 came close (Figure B-10).

Figure B-9. Flooding of village of Ruisbroek in 1976 (Source: FHR)

Figure B-10. Failure of the land-side slope along the Sea Scheldt in 1990 following overtopping (Source: A. Van Hoyweghen)

A storm surge in 2013, announced as a super storm, led to the deployment of temporary water defences and the evacuation of hundreds of people at the coast. Afterwards, vertical cliff up to 2 m were found at the beaches following erosion by waves (Figure B-8).

High river-discharge events

In 1993 and 1995, the discharge of the Meuse twice rose above 3000 m³/s and major flooding occured. In both events, people were asked to evacuate. During these events, the erosive forces of the Meuse became very visible through scour of its floodplain (Figure B-11).

Figure B-11. Scour of the flood plain during high river discharge of the Meuse (Source: H. Gielen)

In 2010, an extreme flood event caused (unforeseen) overflow of the ship canal Brussels – Charleroi (Figure B-12).

Figure B-12. Erosion following overflow along the canal Brussels (top left)– Charleroi in 2010 (Source: K. Van Eerdenbrugh)

Presumably an extra low tide during springtide preceded by abundant rainfall caused a slope failure along the Upper-Sea Scheldt in Schoonaarde (Figure B-13).

Figure B-13. Slope instability in Schoonaarde along the Schelde (Source: De Vlaamse Waterweg nv)

Finally, several hours overflow, although limited in head, resulted in cliff formation at the upper reach of the Durme (tidal tributary of the Sea Scheldt) (Figure B-14).

Figure B-14. Headcut formation following a low-head overflow event along the Durme in 2010 (Source: FHR)

2.4 Legislation and governance in Belgium

2.4.1 Implementation of EU Regulations

The Flemish Decree on Integrated Water Policy was officially approved in July 2003. This decree is the implementation of the European Water Framework Directive and the Floods Directive into Flemish law.

2.4.2 National legislation

The levee act dating from 1979 allows water agencies to take charge of all the necessary works regarding maintenance, strengthening as well as construction of (new) levees, even if not (yet) the owner.

2.4.3 Governance

For the organisation and planning of the integrated water management, the decree on Integrated Water Policy distinguishes the following levels:

1. the River Basin District (Scheldt and Meuse) with the river basin management plans
2. the Flemish region (river basins Scheldt, Meuse, IJzer, Polders of Bruges) with the Water Policy Note
3. the sub-basin (11) with the river catchment management plans, that are part of the river basin management plans.
4. the international coordination for the river basin districts of the Scheldt, resp. the Meuse is assigned to the International Scheldt Commission (ISC) and the International Meuse Commission (IMC) through the treaties of Ghent (03.12.02).

The minister who is responsible for integrated water policy is assisted by the Coordination Committee on Integrated Water Policy (CIW). This commission is responsible for the coordination of the integrated water policy on the level of the Flemish Region.

Flanders is divided into 11 sub-basins. In each sub-basin, there is a common consultative and organizational structure, i.e. the basin management (political consultation between the Flemish Region, the provinces, and the municipalities), the basin secretary (technical-official) and the basin council (social consultation with the stakeholders)

Most of the flood levees in Flanders are owned and managed by the two governmental agencies within the Ministry of Mobility and Public Works: Coastal Division and De Vlaamse Waterweg (Eng. The Flemish Waterway).

Knowledge Network on Dikes

In 2015, a Knowledge Network on Dikes (in Dutch: Kennis Netwerk Dijken KND) was established. Levee and bank managers together with technical services of the Flemish Government joined forces to enhance knowledge exchange and profesionalize levee management in Flanders.

2.5 Guidelines and good practice

Within the framework of public procurement by the Flemish government, a standard tender, called SB260 (in Dutch), is available for all engineering works related to water. Among others, Dutch design guidelines and recently the International Levee Handbook (ILH) are used.

Standard levee profiles are often applied (Figure B-15).

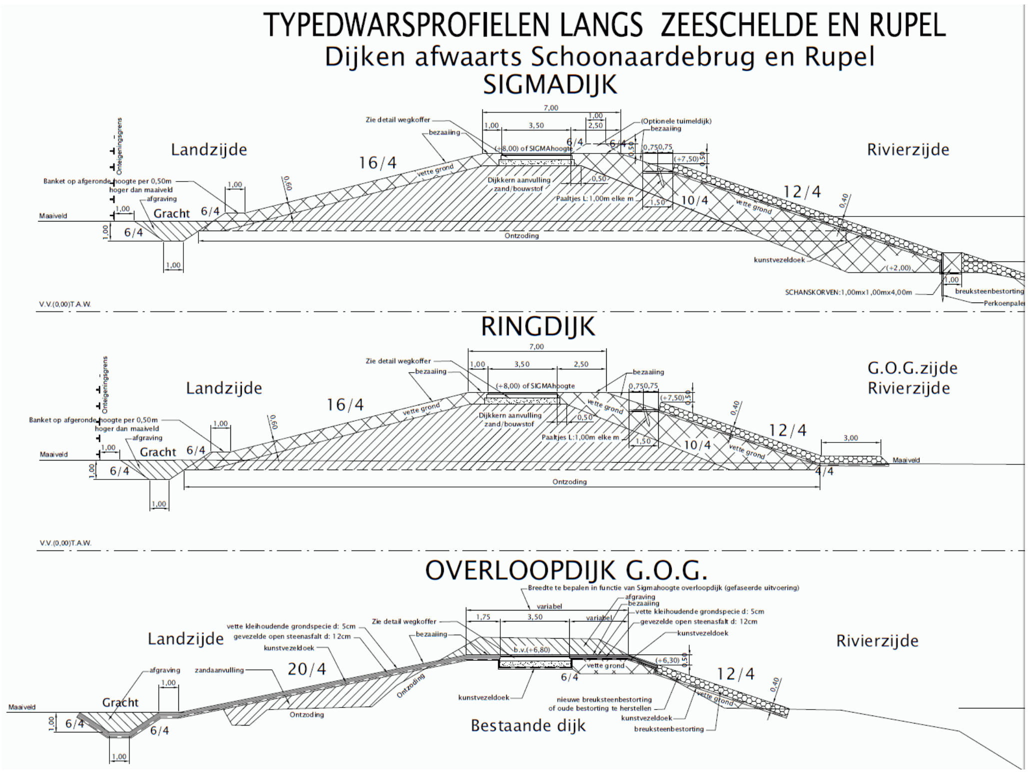

Figure B-15. Standard levee profiles applied within the Sigmaplan (Source: de Vlaamse Waterweg nv)

2.6 Common practices during Levee Life Cycle

The topography and bathymetry are surveyed every 1 to 6 years.

Field inspections of the water defenses are scheduled every 1 to 3 years. Different types of inspections can be performed, e.g. A- (common), B- (expert), O- (occasional) types of inspection.

A safety assessment is executed around every 6 years in order to evaluate the current status of coastal safety. For the other rivers, a weak link identification exercise was carried out around 2010.

Standard levee reinforcement works tend to cost 2 to 4 million EUR/km.

2.7 Critical knowledge and data gaps; critical research needs

The following knowledge gaps and critical research needs were identified from the Belgian point of view:

- Wave propagation, erosion and wave overtopping with shallow and/or vegetated foreland
- Strength of grass cover following wave run-up, impact and overtopping as well as overflow
- Preventing damage from burrowing animal activity (Figure B-16)
- Breach initiation and growth

Figure B-16. Animal activity discovered by coincidence (Source: de Vlaamse Waterweg nv/FHR)

2.8 Summary of key facts

- Up to 700 km of (large) levees of which 10% along the coast, 10% along rivers and 80% under tidal conditions
- Up to 1 million people are protected by water defences to extreme events ranging from 1/500 to 1/10000 years
- Near-failures from the last decades are slowly raising awareness on (improved) levee management among stakeholders
- Agencies within the ministry of mobility and public works take care of the levee management within the framework of the EU Directives
- International and national design guides are used

2.9 References

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3 Czech Republic

3.1 Facts and figures on Czech levees and flood defences

General facts:

The history of building flood protection measures stretches back to middle ages. The principal structures are

- Reservoirs – multipurpose ponds for fish production and also for the protection against flood. One of the largest ponds in Europe – the Rožmberk (built in 1590) is 14m deep with a normal volume of 6.2 million m^3 retained and during the flood in 2002 about 70 million m^3 of flood volume which contributed to the flood protection of Prague.
- Farmer levees built from local material (soil, stones, gravel) to protect agricultural land. In some cases these levees were rebuilt (beginning of 20^{th} century) to standard levees. Unfortunately, inappropriate material remained in the embankment body and significant seepage was identified during past floods (1997, 2002, 2006, 2010, 2013).
- The systematic protection of extensive areas comprising urban and also outdoor areas started in the twenties of the 20th century. Hundreds of kilometres were built along the principal Czech rivers, mostly at the wide floodplains of lower reaches of the Morava, Elbe, Oder and other rivers. There is only poor knowledge about the material of the levees and their sub-base which in many cases consists of highly permeable quaternary gravel sands covered by the topsoil of various thickness (0 - 5 m).

The financing of flood protection measures differs. Since 2003 the so-called “Programme financing” has been in progress. It is guaranteed by the Ministry of Agriculture (MA); the financial sources are provided by European Investment Bank as a loan to the Czech Republic. The process is as follows:

- The subjects who want to be protected submit the application to the Ministry of Agriculture. The applicant appends the preliminary project of the flood protection and also basic information for the assessment of its efficiency.
- An independent “Strategic expert” elaborates the quantitative risk assessment and evaluates quantitative parameters like relative efficiency, absolute efficiency and return period (recovery of investment).
- The future owner will prove the feasibility of the project in terms of the accessibility of the plots for the construction. This may take several years to negotiate the project with land owners.
- For efficient projects, Ministry of Agriculture (MA) provides the loan.
- The corresponding River Agency will run the project.
- After finishing the project it is forwarded to the future owner (municipality, private bodies).

In the Czech Republic (CR) until now there is no central database of existing flood protection measures. This is probably because of numerous bodies which built and “possess” structural flood protection measures in the form of investment. Mostly the technical level and maintenance of flood protection structures correspond to the owner. In general, the owners of flood protection measures can be:

- River Agencies, state enterprises are responsible for overall river basin management, conceptual planning of flood protection measures, etc. There are 5 River Agencies in Czech Republic corresponding to five major river basins – The Elbe, Vltava (Moldau), Oder, Morava and Ohře rivers. These companies have enough professional staff to manage flood protection issues, they are probably the major owner of flood levees and similar structures.
- Municipalities may be owners of local flood protection arrangements like levees, floodwalls, flood attenuation reservoirs including dams, etc. An example may be the flood protection in Prague consisting of more than 20 km of levees, floodwalls, mobile walls including several pumping stations and appurtenant structures (gates, sewer closures, …). Smaller municipalities usually do not possess enough technical staff and operation and maintenance of flood protection measures may be a problem.

- Forests of the Czech Republic, state enterprise are the owners of smaller streams and thus also owners of relevant flood protection arrangements related to these streams. They have their own Departments for Water Management, even if these are only minor and "less important" part of the enterprise and thus underfinanced.
- Private bodies are owners of arrangements protecting private property against floods. These may be private companies, factories, individual inhabitants, etc.

This state makes the development of central summary about levees extremely difficult. A more reliable database is now under construction with the help of major owners – River Agencies. Therefore the data mentioned below are rough estimates only.

Number and type of flood protection measures
In the Czech Republic, it is estimated there are about 4000 km of earthen levees complemented by floodwalls in constrained urban areas. It is estimated that there are surely more than 100 km floodwalls (single hundreds of km) in Czech Republic Floodwalls may reach significant height, e.g. about 4 m in Prague. They are usually provided with slurry walls to assure seepage stability of the sub-base.
Due to aesthetic reasons in urban areas where the river is an important environmental element the flood walls are designed as combined – with fixed (concrete, masonry) part and movable part made of mobile elements like jambs and stop-logs (nowadays made of aluminium).
Practically at each separately closed locality, the arrangement (stable or mobile) for pumping of inner waters (rainfall, sewage, seepage) during the flood is installed. Pumping stations are frequently designed as mobile to be able to serve for several localities. At the same time-gated sluices or culverts are installed in levees to empty the areas behind the levees after the flood. These arrangements are installed also in case of crossing levees with local tributaries.
During last two decades, more than one hundred "dry reservoirs" for trapping local (mostly flash) floods were constructed in the Czech Republic. These are mostly so-called "small reservoirs", i.e. dam up to 9 m height, volume up to 2 mil. m^3.
There are several polders (less than 50) located at the floodplains adjacent to the streams with significant flood attenuation volume.

Technical arrangement
In the Czech Republic, the construction principles related to the flood protection arrangements have developed continuously in accordance with increasing demands for protection against floods. Recently, regulations have become fragmented into a great number of laws, amendments, national technical standards and guidelines. In this text, the current system of flood protection legislation in the Czech Republic is briefly described, and some comments are mentioned about the present system.
The levees are constructed as earthen, usually homogeneous, exceptionally as zonal with clayey core and shoulders. Traditionally they have no sealing of the sub-base (slurry wall) and toe drain. Dominantly they are built in relatively unique geological conditions where the fluvial sands (or sandy gravels) are covered by relatively impervious topsoil layers making protection against seepage. The problems may occur in cases of engineered rivers where levees cut former meanders and where original geological conditions are disturbed.
In the Czech Republic the following principles are used in the design of levees:

- the width of levee crest should not be less than 3 m and is governed by the utilisation of the levee crest (footpath, service road, public road, etc.),
- the use of soils according to the type and structure of the levee is in Table CZ-1,
- recommended upstream and downstream slopes according to the type of levee and soil used are summarized in Table CZ-2.

Table CZ-1 Applicability of soils for the types of levees (ČSN 75 2310 – Czech national standard)

Soil symbol	Soil type	Homogen.	Sealing	Shoulders
GW	well graded gravel	not suitable	not suitable	excellent
GP	poorly graded gravel	not suitable	not suitable	excellent
GM	silty sandy gravel	excellent	quite suitable	less suitable
GC	clayey sand gravel	excellent	excellent**)	less suitable
SW	well graded sand	not suitable	not suitable	suitable*)
SP	poorly graded sand	not suitable	not suitable	suitable*)
SM	silty sand	suitable	suitable	not suitable
SC	clayey sand	quite suitable	excellent	not suitable
ML	inorganic sandy silt, very fine sand	less suitable	less suitable +)	not suitable
CL	inorganic clay with low to medium plasticity	suitable	quite suitable	not suitable
OL	organic sandy loam	less suitable	less suitable+)	not suitable
MH	inorganic loam	less suitable	less suitable+)	not suitable
CH	inorganic high plasticity clay, fat clay	less suitable	less suitable+)	not suitable
OH	organic clay with medium to high plasticity	not suitable	not suitable	not suitable
*) for gravel soils , **) special care on weathered particles , +) not suitable for upstream sealing				

Table CZ-2 Slopes of individual types of levees (ČSN 75 2410– Czech national standard)

Type of soil sealing	Soil classification		Slopes	
	Sealing	Shoulders	upstream	downstream
Thin	GM, GC, SM	rockfill	1 : 1,75	1 : 1,5
	SC, CG, MG	GW, SW	1 : 2,8	1 : 1,75
	ML-MI, CL-CI	GP, SP	1 : 3	1 : 1,75
Wide	GM, SM	rockfill	1 : 3	1 : 2
	GC, SC, MG, CG, MS, CS	rockfill GW, GP	1 : 3 1 : 3,2	1 : 2
	ML-MI, CL-CI	SW, SP	1 : 3,4	1 : 2,2
Homogeneous levee *)	GM, SM		1 : 3	1 : 2
	GC, SC		1 : 3,4	1 : 2
	MG, CG, MS, CS		1 : 3,3	1 : 2
	ML-MI, CL-CI		1 : 3,7	1 : 2,2
*) For levees smaller than 4 m the slope can be increased to 1 : (*x* - 0,5)				

Hydrology

The latest experience comes from the following floods in the Czech Republic:

Time	Type of the flood	Fatalities	Material loss (USD)
1997 - July	Regional - summer	49	1.91E+09
1998 - July	Local – flash flood	10	6.18E+07
2000 - March	Sub-regional, snow melting	2	1.03E+08
2002 - August	Regional - summer	17	2.32E+09
2006 - spring	Regional – snow melting	11	2.74E+08
2009 - June	Local – flash flood	18	3.21E+08
2010 - May, June	Regional	8	2.45E+08
2013 - August	Regional	15	1.00E+09

Most of these floods locally exceeded 100 year return period and in 1997, 2002, 2009, 2013 exceeded 500 year return period. The design return period for levees is from 20 years (smaller towns) to 100 years (larger cities usually with a population exceeding 100 000 inhabitants), exceptionally 500 years (Prague with historical monuments and subway).
Corresponding height of levees (floodwalls) is from 0.5 to 4.5 m according to local conditions. Usual freeboard is from 0.3 to 0.70 m. Sometimes uncertainty of the design discharge is used instead of a fixed freeboard (e.g. increase of design discharge by 30%).

Performance and maintenance of levees
The regular maintenance of levees consists mostly of grass cutting. Other spending is not regular and is usually linked to the flood situation and the damage of the levee.
Extensive damage is also identified due to the activities of burrowing animals, such as the European beaver. The repair of the levees at the Dyje river cost about 2 mill EUR/km. The vegetation on the levees damaged by beavers was restored with a cost of approximately 10 thsd EUR/km.
Flood damage of levees are not expressed separately. The flood damage and financial means necessary for the repair works are funded by the government after each extreme flood and include sources for the repair of river bed, levees and structures at the rivers (bed drops, revetment, weirs, conduits, ...). For example, the 2013 flood losses related to the water courses (including levees) - corresponding to repair works - were about 90 million EUR.

The Water Act 254/2001 Sb. excludes planting wooden species on the levees. Also, the levee owner has to clear away all self-seeded wooden plants except historical trees or protected plants and herbs. For the treatment, maintenance and protection of vegetation it is possible to apply the Guideline on maintenance of vegetation on small embankments (Section 2.4). It is necessary to systematically remove bushes, self-seeded plants, young trees and evidently dead, ill or uprooted trees. Trees endangering dike safety, damaging levee lining or structures in levees (sluices, spillways) and restricting access to levee crest and slopes are unacceptable. Trees should be also removed if they decrease capacity of channel, berms or floodplain upstream of levees. Vegetation also should not constrain technical surveying and geodetical measurements.

3.2 Protected value, safety standards and flood risk

Design flood
There are no strict requirements on the design flood (return period) for individual land use categories. However, historically some guidance is anchored in older and also in presently valid (but not obligatory) national standards. In tables CZ-3 and CZ-4 recommended design flood return periods are linked to particular land uses according the older Czech national technical standards.

Table CZ-3 Design flood discharges for river treatment purposes according to ČSN 73 6820 (1973)

Land use	Design discharge for channel capacity
Continuous urbanisation, industry area, important roads, infrastructure	> Q_{50}
Valuable arable land, vineyards, hop gardens, etc.	> Q_{20}
Arable land	Q_5 to Q_{20}
Meadows, pastures, forests	Q_2 to Q_5
For stability and resistance of levees	Q_{100}

Table CZ-4 Design flood discharges for river treatment purposes according to ODN 75 2103 (1993)

Land use	Design discharge
Historical town centres, historical monuments	$\geq Q_{100}$
Continuous urbanisation, industry area, important roads, infrastructure	$\geq Q_{50}$
Dispersed built up area (residential and industrial), continuous recreational areas (cottages, etc.)	$\geq Q_{20}$
High value land like orchards, hop gardens, etc.	$\geq Q_{20}$
Arable land (according its bonification)	Q_5 to Q_{20}
Pastures and forests	Q_2 to Q_5

In 2000 the Strategy for the Flood Protection for the Territory of the Czech Republic was issued. Later on the Documentation of the programme 129 120 ”Support of the prevention against floods II“ was published by the Ministry of Agriculture of the Czech Republic. According to these documents the following factors should be taken into account when deciding about the design flood return period N:

- the necessity of flood protection with respect to the lowering of damage and loss on human lives and material property,
- appropriate flood protection level should be determined using the risk-based methods with respect to the following criteria:
  - the population at risk,
  - the value of the property and potential material losses,
  - the occurrence of important structures and strategic facilities in the endangered area (principal highway, railway, gas duct, power plants, etc.),
  - the celerity of the flood and warning time available (especially at flash flood-prone areas),
  - data about sediment transport,
  - water sources and water supply infrastructure,
  - water pollution sources like wastewater treatment plants, industry handling with dangerous toxic substances,
  - general feasibility of flood protection arrangements (agreement of landowners, other conflicts),
  - impact on nature, landscape, and cultural heritage,
  - economic effectiveness of the arrangements.

Resulting recommendations according to the Strategy for the Flood Protection for the Territory of the Czech Republic are shown in table CZ-5.

For the design of river channel and flood protection measures (levees, floodwalls) , hydrologic uncertainties should be taken into account. In the Czech Republic, these are quantified according to the “accuracy class” at the standard ČSN 75 1400 via standard error (Table CZ-6). Uncertainties can be considered e.g. by a corresponding increase of the design discharge or taken into account when designing levee freeboard.

Table CZ-5 Design flood discharges according to the Strategy for the Flood Protection for the Territory of the Czech Republic

Land use	Design discharge
Historical monuments	$\geq Q_{100}$
Public roads	according importance Q_{20} to Q_{100}
Continuous urbanisation, important industry area,	Q_{100}
Larger built-up areas or manufacturing, services	Q_{50} to Q_{100}
Smaller urban areas	Q_{20} to Q_{50}
On-purpose roads	Q_{10} to Q_{50}
Orchards, gardens, hop gardens	Q_{10}
Arable land	Q_5
Meadows, forests, pastures	Q_{30d} to Q_1

Table CZ-.6 Characteristic error in provided hydrologic data

Hydrological data	Accuracy class			
	I	II	III	IV
	Standard error [%]			
Average annual discharge (Q_a)	8	12	20	30
M – day´s discharges (Q_{30d} to Q_{300d})	10	15	25	40
M – day´s discharges (Q_{330d} to Q_{364d})	20	30	45	60
N – year´s discharges (Q_1 to Q_{10})	10	20	30	40
N – year´s discharges (Q_{20} to Q_{100})	15	30	40	60

Check Flood

According the article I, §5, sect. (6) of the Decree 367/2005 Sb. it is required that during a flood that water structures (dam, levee, dry reservoir) pass the so-called "check flood" according to Table CZ-7. Levees, polders and dry reservoirs and are considered to be structures damming water during the floods and have to satisfy these requirements similarly to dams with permanent storage.

Table CZ-7 Required return period of check flood for water structures

Loss	Description of consequences	Annual probability	Return period
		$P \approx 1/N$	N
Extremely high	Considerable loss of human lives	0.0001	10 000
	Fatalities improbable	0.0005	2 000
High	Expected single fatalities	0.001	1 000
	Fatalities improbable	0.005	200
Low	Losses downstream of water structure, no fatalities	0.01	100
	Losses only for the owner, other losses minor	0.02–0.05	50–20

Freeboard and levee spillways

Uncertainties related to hydrologic data, inaccuracy of geodetic data, hydraulic model and also the importance of the flood protection measures govern the height of freeboard. According to the Decree 590/2002 Sb. and 367/2005 Sb. it is required to assume the freeboard height 0.3 to 1.0 m at the protection against $Q_{100.}$ At lower flood protection levels the freeboard should be up to 0.5 m. As mentioned above, consequences in case of levee breaching should be taken into account together with the other factors mentioned. Generally, the freeboard height should not compensate uncertainties that have been taken into account e.g. by increasing design discharge according to the table CZ-6. Another important factor is expected settlement of the dike which from experience could reach 0.4 % to an extreme of 1 % of levee height.

In the case of protection lower than Q_{100}, the protection against levee breaching due to overtopping should be assured according to the Decree 590/2002 Sb. At the same time, the levee should satisfy the requirements related to check flood (table CZ-7).

In case of international or boundary streams the freeboard height has to be co-ordinated based on transboundary negotiations and agreement.

In areas vulnerable to subsidence the statements of the standard ČSN 73 0039 should be taken into account. The levee crest has to be designed including overelevation related to the expected land subsidence or with the possibility of a rapid increase of its crest level. It is recommended to propose levees with a wider crest with the corresponding stock of appropriate earth. The subsidence forecast should be verified periodically by visual inspections and geodetical surveying.

3.3 Recent major floods and (near-)failures of levees

The more detailed analysis was carried out at the Morava River Basin where about 1300 km of levees were analyzed. The summary of levee failures was done for the period 1965 - 2004, i.e. about 40 years. The percentage of identified primary reasons of failures are shown in Figure CZ-1. The analysis showed that there were 153 levee failures during the studied period. The relative frequency of failures per 1 km was 0,118, the annual frequency per km was 0,00295 failures/km/year.
The number of failures fit well to the return period of individual floods (Figure CZ-2). This also reflects the design level of the flood protection. It can be seen that the most of the failures occurred during the flood in 1997 when the return period exceeded locally 500 years. Episodes at which only a minimum of levees failed are also visible in Figure CZ-2.
It is obvious that the statistics cannot be applied generally to the flood risk analysis.

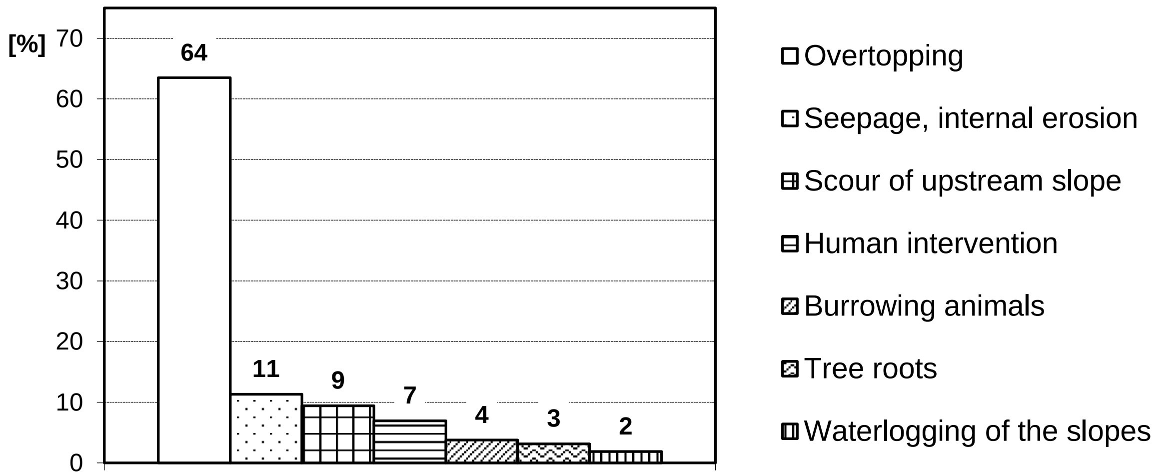

Figure CZ-1 The percentage of reasons of levee failures in the Morava river basin

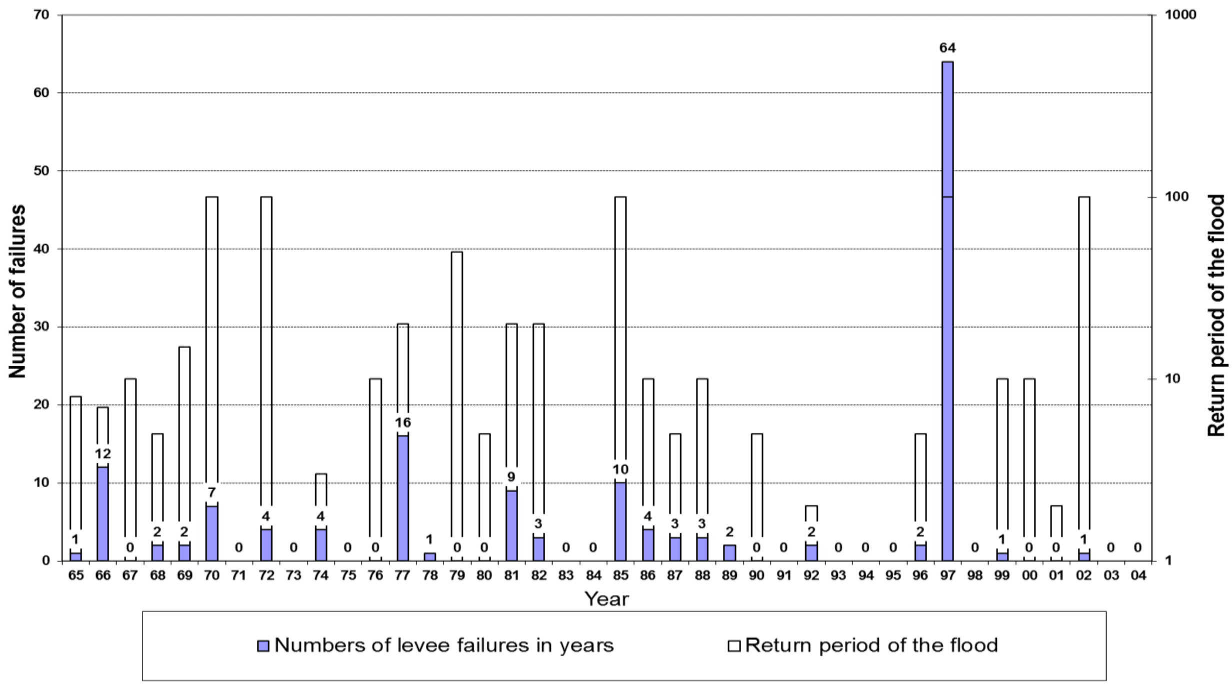

Figure CZ-2 The number of levee failures in the Morava river basin vs. year and return period

3.4 Legislation and governance in the Czech Republic

In the Czech Republic the construction principles and legislation related to the flood protection arrangements have developed continuously in accordance with increasing demands for protection against floods. Recently, regulations have become fragmented into a great number of laws, amendments, national technical standards, and guidelines.

In the Czech Republic, the construction of modern concept flood protection measures began at the end of the 19th century and practically is not finished until now. The legislation has developed gradually with increasing demands for the safety and reliability of flood protection systems. The legal basis for the monitoring and supervision of related structures was established in the seventies of the last century and in some aspects took ICOLD recommendations into account in some areas.

Today, design standards and safety regulations for water structures (including dams and flood protection works) are fragmented into a relatively great number of laws, announcements, technical standards, and guidelines. Due to gradual elaboration and abundant changes during this period some minor inconsistency occurs in individual statements and requirements.

In fact, in the legislation, there is no formal difference between dams and levees. The legislation (Water Act) distinguishes so-called "specified water structures" which may cause major financial losses and fatalities when failed. They are obligatorily subject to categorization (4 categories = consequence classes) which governs the particulars of technical surveillance (extent, measured variables, frequency, etc). Experience shows that levees are classified as category 4, exceptionally category 3 while dams fall into categories 1 or 2.

EU Floods Directive projects only include conceptual issues like the level of flood protection, efficiency assessment, flood risk analysis etc. There is no guidance on the structural issues of levees, surveillance, etc.

In Czech Republic, the key player in levee design is still the state (Ministry of Agriculture and Ministry of Environment). River Agencies have the role of "river basin planner" and always give their official statement on the proposal when planning any new flood protection measure in the catchment. When purchasing the assets from the land owner for building new levees, the key role is played by the local authorities, the municipalities which will be protected. This is mostly the key issue in flood protection development and sometimes is a limiting factor. The maintenance and operation belong to the owner of the installation. This may be a private body, municipality, Forests of the Czech Republic, river agency.

3.4.1 Implementation EU Regulations

Procedures for flood risk analysis have been developed in the Czech Republic since the catastrophic floods of 1997 in line with European and worldwide trends and have been tested and applied in hundreds of case studies to date. In the past decade, the Flood Risk Directive Guideline based on past experience with flood risk analysis applications was processed. The more detailed information may be taken from Dráb, Říha (2010).

The Flood Risk Directive requires three stages of flood risk management (see details in Sect. 2):
1. Preliminary flood risk assessment.
2. Creation of flood hazard and risk maps for various scenarios.
3. Development of flood risk management plans.

During the implementation of the Flood Risk Directive (ES, 2007), currently used flood risk assessment methods are being employed. At present, a detailed description of these methods is part of the Guidelines (MA CR, 2009) which have been elaborated.

3.4.2 National legislation

The legislation does not differ for dams and levees. the difference is anchored in the categorization of hydraulic structures. The overview of classified hydraulic schemes into categories is shown in table CZ-8. It can be seen that only two levees are classified as category II, 58 levees as category III, The others belong to category IV.

Table CZ-8 The summary of hydraulic structures and categories (issued 2014)

Category	Type of the hydraulic structure						Total
	Dam	Weir + hydropow.	Tailing dam	Levee	Penstock	Hydropower	
I.	27	-	-	-	-	-	27
II.	52	3	7	2	2	1	67
III.	212	44	18	58	4	5	341
Totall hydraulic structures in category I. – III.							435
Comment:	There are about 20 000 hydraulic structures in Category IV (levees, small dams, weirs, etc.)						

Laws
The two principal legal documents concerning construction, administration, and control of water management in the Czech Republic are the Civil Engineering Act and the Water Act.
The Civil Engineering Act (Building Code) defines general rules in landscape and urban planning, development, construction, and maintenance of civil structures, including water structures and flood protection measures. The Act regulates preparation procedures and building permits and defines restrictions, liability and ownership demands in the development of civil structures in general. Since 2007 an amendment of the Civil Engineering Act substituted the original law (1976).

The Water Act deals with the administration, ownership, control, and use of water as a resource. Of great importance is the part dealing with watercourses and water structures, the responsibility of their owners and the obligation to carry out the supervision and inspection of hydraulic structures. The improved extensive part including numerous paragraphs deals with various aspects of flood protection. The last amendment of the new Water Act (from 2001) was issued in late summer in 2010 in which the implementation of European directives was made.

Decrees and technical standards in flood protection
Decrees have lower force in the Czech legislation hierarchy than laws; however, their statements are obligatory. The following are closely related to the flood protection:

- Decree concerning technical-safety supervision of water structures.
- Decree concerning particulars of the handling rules and operational rules for water structures
- Decree concerning technical requirements for water structures.
- Decree concerning the delimitation of flood zones.
- The set of laws and decrees concerning emergency activities during floods.

Technical standardisation was organised in Czechoslovakia from the beginning of the 20th century. In 1951 the responsibility for technical standardisation was taken over by the state administration through the Institute for Standardisation. The previously voluntary standards became obligatory under the law. The new legislation defined technical standards as non-obligatory from 1995 again. The exceptions are the statements of laws and decrees referring to technical standards or the decrees of bodies entrusted by law to order standards to be obligatory.

Technical standards in flood protection structures (such as levees) have been elaborated since the nineteen-sixties. The set of standards dealing with flood protection included topics like river engineering, weirs, calculation of wave effect, construction of embankments, the design of outlets and intakes, stability computations for embankments, measurements and observations for water structures, the set of standards for dam engineering, etc.
Over time, most of the standards were improved and transformed into the Czech National Standards, which were periodically updated. Extensive improvement and updating of standards have been carried out approximately since the year 1987. Some standards have also been issued as "Technical standards for water management". In accordance with requirements for new types of structures (e.g. dry reservoirs, etc.) some new standards have been issued as well.

Dam standardisation in the Czech Republic has a long tradition with its roots in water management and construction advances from the end of the 19th century. On the other hand, from the list shown above, which is not complete (it does not include standards for soil mechanics, hydrology, etc.), it is clear that knowledge and experience are dispersed across a great number of documents.

Problems with some aspects of flood-related legislation, standardisation, and technical surveillance

The general framework for flood protection structures design, construction, maintenance, and safety assessment is defined by the obligatory statements of corresponding laws and decrees. More detailed requirements are anchored in the statements of technical standards and guidelines. Unfortunately for the user, it is quite difficult to implement the complex system of standards and follow up its development and all cross-references between individual standards and legislative documents. Moreover, due to the time factor over the course of the elaboration and publication of laws, decrees, and standards some inconsistency occurs in terminology and sometimes also in individual statements.

Differences can also be found in the safety supervision of flood protection structures when compared with European and worldwide practices.

The specific problem consists in the method of elaboration of decrees and standards. In most cases, the wider professional community is engaged in the discussion only as a formality. The active standard-negotiation process is time-consuming and sometimes also necessitates expenses for which the participating external professional bodies are not compensated. Therefore, as a rule, only a few professional subjects respond regularly to interim proposals for standards and take part in the negotiations involved.

3.4.3 Governance

Water authorities are located in cities of greater importance, where environmental departments are responsible for activities in the field of water management. In the case of larger flood protection schemes, this position is held by regional authorities.

The central water authority is the Ministry of Agriculture (MA). The responsibility of the Ministry of Agriculture extends to water management activities and care for water management infrastructure. According to the Water Act, the Ministry of Environment has a wide range of competence, which covers flood protection or hydrometeorological forecasts.

The principal owners of flood protection facilities are usually the River Board state agencies. Only a minority of flood protection infrastructure belongs to municipalities. Watercourses of lower importance and small dams are managed by Forests of the Czech Republic and exceptionally to local municipalities and other owners (water supply companies, etc.).

Decree No 241/2001 Coll. is the key mandatory document concerning technical-safety supervision of water structures. The governance and surveillance are carried out according to the category of the hydraulic scheme.

3.5 Guidelines and good practices

In general, no ICOLD bulletin is directly applied to Czech documents. Particular ICOLD experiences and recommendations are gradually and slowly projecting into technical standards when they are amended. For levee´s planning, design and operation following documents are used:

Obligatory:

- Decree 471/2001 Sb. concerning technical-safety supervision of water structures.
- Decree 195/2002 Sb. concerning particulars of the handling rules and operational rules for water structures.
- Decree 236/2002 concerning the delimitation of flood zones.
- Decree 367/2005 Sb. concerning technical requirements for water structures.

Recommended:

Technical Standards:

- ČSN 72 1006 Control of soil compaction (1998).
- ČSN 73 0039 Design of structures on the undermined areas. Basic requirements (1989).
- ČSN 73 1000 EN 1997 Eurocode 7. Geotechnical design (2006).
- ČSN 73 1001 Foundation of structures (1988).
- ČSN 73 1208 Design of concrete water structures.
- ČSN 73 6110 Design of local roads (2007).
- ČSN 73 6201 Design of bridges (1995).
- ON 73 6821 Lining of banks of water courses (1974).
- ON 73 6827 Vegetation at watercourses (1974).
- ČSN 75 0250 The load on water structures (1990).
- ČSN 75 0255 The action of waves on water structures (1987).
- ČSN 75 1400 Hydrological data (1990).
- ČSN 75 2101 Ecologization of water courses (1993).
- TNV 75 2102 Treatment of streams (1995).
- TNV 75 2103 Treatment of rivers (1998).
- ČSN 75 2130 Crossing and passing of water courses with railways, roads and lines (2000).
- TNV 75 2131 - Outlets and intakes for water structures (1999).
- ČSN 75 2410 Small embankments (2011).
- TNV 75 2415 Dry reservoirs (2002, 2006).
- TNV 75 2910 Operational rules of water structures on water courses (1994).
- TNV 75 2931 Flood protection plans (2001).
- TNV 75 2935 Assessment of safety of water structures during floods (2014).

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3.6 Common practices during Levee Life Cycle

Design practice and cost of reinforcement (per km or per object)
It is always difficult to specify costs for levees as they differ in their height, foundation conditions, seepage regime, crossing with other linear structures (railway, motorway, conduits etc).
As approximate values for the Czech Republic are:

- maintenance of plain surface of levees (cutting grass, small vegetation) - 1-2 thsd EUR/km/year
- maintenance of more complicated reaches (crossing, dismantling of the railway etc) - several million EUR/km/year

Inspection of levees
It is carried out according to the Category. In category IV, only visual inspections are carried out annually, during and after each flood event. During last decade the geophysical measurements are gradually performed namely along critical reaches (crossing past meanders, crossing with conduits, etc.) to identify critical sections.

The safety supervision is executed as follows:

- Periodical and "after the flood" inspections are carried out as a part of a normal operation by the owner´s staff.
- The second inspection level in the case of important flood protection schemes is carried out by a single private agency with the highest level of authorisation by Ministry of Agriculture and qualified staff. The advantage of such a system is that it allows long-term systematic inspection. The result of this periodical supervision and monitoring is a report assessing the safety of each structure, and proposals for its improvement. For the monitoring of levees of lower importance, the owner is obliged to appoint a certified body for dam safety supervision. In the Czech Republic, 11 companies and agencies are holders of such certification.
- The third level of a safety inspection is assumed to be an independent check mechanism. In the Czech Republic, the responsibility belongs to the state administration officers. Due to the wide range of problems concerning state control in water management, the qualifications and specialisations of state regional and governmental officers are sometimes not adequate to the task required of them. There is no existing system of qualification requirements and periodical certification of expertise in flood protection and construction in water management.

Maintenance and safety assessment
Safety assessment of existing levees is normally not performed. During the design, the safety assessment is carried out to identify the safety factor for structural failure (sliding surface), for seepage and internal erosion failures. When appropriate, the spillways in the levees are newly designed and built to protect them against uncontrolled overtopping and breaching.

Flood event management
In case of flood danger, during and after the flood the "flood committee" starts its work. The committees operate at several levels (state, district, municipality, river basin etc) according to the

extent of the flood. The members of the committees are representatives of state authorities, rescue services - fire brigade, river agency, hydrological services, technical surveillance, etc.
The following situations are considered as situations posing flood danger:

- specified limit of the water level or flow in a watercourse is reached and the increase tends to continue,
- heavy rain falling for a long period of time, forecasted occurrence of intensive precipitation or snow melting, dangerous movement of ice or occurrence of dangerous ice jams and blockages,
- the emergency situation of a water management structure posing a danger that the structure may become damaged.

Flood Protection Measures:

1. Preventive measures and measures in situations posing flood danger are
    - determination of floodplain areas
    - specification of limits for flood protection activity degrees
    - flood protection plans
    - flood protection inspections
    - organisation of flood forecasting and reporting services,
    - organisational and technical preparation
    - creation of flood reserve stock
    - clearing of floodplain areas
    - training of persons participating in flood protection activities,
    - activities of the flood forecasting service,
    - activities of the flood reporting service
    - warning in cases of danger of floods,
    - establishment and activities of the watching service,
    - flood recording and documentation.
2. Measures taken during flood are
    - regulation of flow regime,
    - flood protection activities (sandbags, provisional construction activities, antiseepage measures),
    - flood rescue activities,
    - activities aimed at ensuring substitute functions and services in territories affected by floods.
3. Flood documentation and assessment including the assessment of damage caused by flood, causal factors adversely affecting the flood, efficiency of adopted measures and proposals for amendment to flood protection measures constitute an integral part of flood protection measures.
4. Construction, maintenance, and repair of structures and other installations for flood protection, as well as investments evoked by floods, are not considered as flood protection measures according to the Czech Republic Water Act.

3.7 Critical knowledge and data gaps; critical research needs

In the Czech Republic there exists no systematic central information about the extent of flood protection measures, its behaviour during the floods, levee failures and failure modes, flood losses due to the levee collapse, etc.

3.8 Summary of key facts

- About 4000 km of levees including floodwalls. The number of structures is not identified, estimate to be several hundreds,
- 90 % along rivers, 10% along streams
- Protected value to be identified,

- Safety standard is not unique, according to the property in floodplain; it is determined by the cost benefit analysis using risk methods,
- Failures mostly due to overtopping and internal erosion, many a times close to the conduits in the levee.
- Guidelines - mostly technical standards and national guidelines.

3.9 References

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Law about nature and landscape preservation 114/1992 Sb.
Environmental Impact Assessment Law 100/2001 Sb.
Water Act. 254/2001 Sb. (since 2001), latest amendment 273/2010 Sb.
Building Code 183/2006 Sb.
Law about the emergency management 240/2000 Sb.

Decrees
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4 England

4.1 Facts and figures on levees and flood defences

In England, there are about 8500 km of flood defences, both Levees and hard structures such as flood walls. There are also about 22000 hydraulic structures such as gates, pumping stations, closure structures and flapped outfalls. The dominant flood risk for these flood defences are from the sea 12%, from estuaries, 18% and from rivers 70%

Most levees have a height between 1 and 6m. They are usually earthfill with grass-cover and may include additional protection such as stone riprap, geogrids and geotextiles. Embankments constructed in the recent years are likely to contain a clay core. The width of the crest is normally determined by asset management requirements, with widths of 2m to 5m being the normal range.

In England, Flood Risk Management activity is primarily funded by the taxpayer. Expenditure for 2016/17 totalled £877m: £795m from central government, £27m from local levies and £55m from other sources, including partnership funding. In addition to this funding, there is further funding that does not come through central government. This includes the proportion of partnership Internal Drainage Board funding raised directly from drainage charges and special levies; and further spending by local authorities.

Decisions on England's overall level of funding for FRM are supported by Long Term Investment Scenarios which model the impact of different funding scenarios to support investment decisions. Decisions on the allocation of funding for individual flood defence schemes are informed by a cost benefit analysis, but also take into account other factors.

A six year capital programme was put in place in 2015/16, supported by central government funding of £2.3bn. At least 15% extra will be provided through partnership contributions from the public and private sectors. There is also a commitment to provide another £211m per year for maintenance, from 2016/17 to 2019/20. The overall cost-benefit ratio of England's capital programme for flood defence schemes was 9.8 to 1 between April 2011 and March 2015. The six year capital investment programme is expected to deliver better protection to 300,000 households and an additional £30.3bn benefits to society.

4.2 Protected value, safety standards and flood risk in England

There are 2.4 million properties at risk from flooding from rivers and the sea. 748,000 of these have at least a 1% annual likelihood of experiencing flooding. A further 3 million properties are at some risk from surface water flooding in England, around 772,000 of which are at or above the 1% annual likelihood level. About 600,000 properties are at risk from both sources of flooding. Surface water is also a significant risk with 4 million properties at risk (1 million are also at risk of sea/river flooding). (Figures from LTIS 2014).

Assets are classified as high, medium and low risk according to probability of failure and consequence of failure. The Environment Agency carries out detailed visual inspections on all assets on main rivers and the coast that contribute to flood risk management. This includes assets that they maintain and assets that other people maintain. The frequency of inspections depends on the risk of assets failing, ranging from six months for the highest risk assets to five years for the lowest risk assets. Inspectors use published inspection standards to grade assets between 1 an 5, where 1 is the highest condition and 5 the lowest.

Table E1 From National Flood Risk Assessment (Figures from NaFRA)

	Residential	Non-residential	Residential	Non-residential
High	153,000	91,000	209,000	73,000
Medium	350,000	153,000	388,000	102,000
Low	1,274,000	329,000	1,809,000	423,000
Very Low	72,000	21,000	Not assessed	Not assessed
Total	1,849,000	594,000	2,406,000	598,000

We estimate the average annual economic consequences of flooding, based on the likelihood of these properties flooding, to be about £960 million from the river and coastal flooding and coastal erosion, and £290 million from surface water flooding.

Over 7100 electricity substations in the floodplain (14% of the total in England). Over 50% of sewage treatment works and 28% of gas infrastructure sites are at risk.

The flood risk assets themselves have a total value of £30 billion. They protect property (homes, businesses, infrastructure). Over the period of 2016 to 2021 we plan to better protect 300,000 houses plus businesses, infrastructure, and land at a cost of £2.3billion bringing benefits of £30.3billion

The Thames Barrier and associated defences protect £200 billion of property and other assets. This is by far the largest of our systems of structures.

There are other urban barriers each protecting multi-million pounds worth of property
A total of 1.2 million hectares of agricultural land in England are at flood risk. However, 84% of the best and most versatile land (grades 1, 2 or 3) is in low flood risk areas, and only 1% of grade 1 land is at very significant risk of flooding.

4.3 Recent major floods and (near-)failures of levees

Flooding is the most common and the most expensive natural hazard in the British Isles. The cost of flooding and of managing floods has been estimated at around £2.2 billion per year. Significant flooding in recent years includes,

- 1998 – Easter floods – 5 fatalities, £400m damages
- 2000 – 10,000 properties flooded
- 2007 – 48,000 residential properties flooded, 7,300 commercial properties flooded, 13 fatalities, £3 billion damages
- 2013/14 - 11,000 properties in the East Coast surge and southern England floods, £1.3billion damages
- 2015/16 – 20,000 properties across Cumbria, Lancashire and Yorkshire

Table E2 Notable floods in England from 1998

2015/16	Cumbria, Lancashire and Yorkshire	20,000
2013/14	Winter Floods (Dec13 to May 14)	11,000
2012	2012 Floods (Mar-Dec)	7,900
2010	Cornwall November 2010	250
2009	Cumbria November 2009	1,500
2008	MorpethSeptember 2008	1,250
2007	Summer 2007	55,000
2006	Thames August 2006	190
2005	Cumbria January 2005	2,500
2004	Boscastle August 2004	60
2003	Thames December 2002 -January 2003	700
2001	Thames October 2001	110
2001	Thames February 2001	120
2000	Thames December 2000	240
2000	Autumn 2000	10,000
1998	Easter 1998	4,500

There have been very few asset structural failures as a result of high water levels and flows during floods. Failures are relatively rare despite the fact that many recent floods have been well above the design load for many of the defences. During widespread flooding in 2007, flood waters put about 9% of raised defences under load. We recorded very few structural failures, representing less than 0.2% of the defences that were loaded. After each major flood we review how our assets performed and analyse any structural failures to allow us to learn, and improve future performance.

In the winter floods of 2013/14 there were 13 reported failures of embankments, six of which were separate breaches along a single six kilometre-long asset. Investigations show that these assets were in condition grades 2 to 4 with just over half in condition grade 4. These failures were mostly after overtopping causing rear face erosion

In Winter 2015/16 6 fluvial levee breaches and 2 coastal structural failures were recorded despite record rainfall creating record flows in many rivers.

The most common causes of failure over the past 10 years have been rear face erosion of steep embankments following overtopping or preferential flow paths created at local irregularities or transitions (for instance a change in flood defence structure or of protection revetment, internal cross section, construction materials or foundation materials). Breaches generally only occur on low consequence, historic assets which often had no formal design.

Figure E-1 Damage to levee at Cley, North

4.4 Legislation and governance

4.4.1 Implementation of EU Regulations

The legislation was debated in Parliament resulting in the passing of national Acts, for example, Flood and Water Management Act 2010.

4.4.2 National legislation

The main legislation affecting the management of Levees and Flood in England is Land Drainage Act 1991, Water Resources Act 1991 and Flood and the Water Management Act 2010 (FWMA). Local bye-laws in addition to these Acts allow serving of notices for infringements.

The Flood and Water Management Act came into force in 2010 in England and Wales. The Act implemented some of the proposals in three previous strategy documents published by the UK Government - Future Water, Making Space for Water and the UK Government's response to the Sir Michael Pitt's Review of the Summer 2007 floods. The Act gave lead local flood authorities (LLFAs) in England and Wales the lead role in managing the risk of all local causes of floods. The Act also gave the Environment Agency responsibility for an overview of flood and coastal erosion risk management.

Owners and Operators of reservoirs, including dams, have legislative duties on safety where they come under the terms of the Reservoirs Act 1975 (amended by the Flood & Water Management Act 2010). These have strict criminal liability.

4.4.3 Governance

Roles & responsibilities are set out in National Strategy.

The role of central government is:
- Department for the Environment Food & Rural Affairs (Defra) – FRM Policy;
- Department for Communities and Local Government (DCLG) – Spatial Planning Policy;
- Cabinet Office – Civil contingencies.

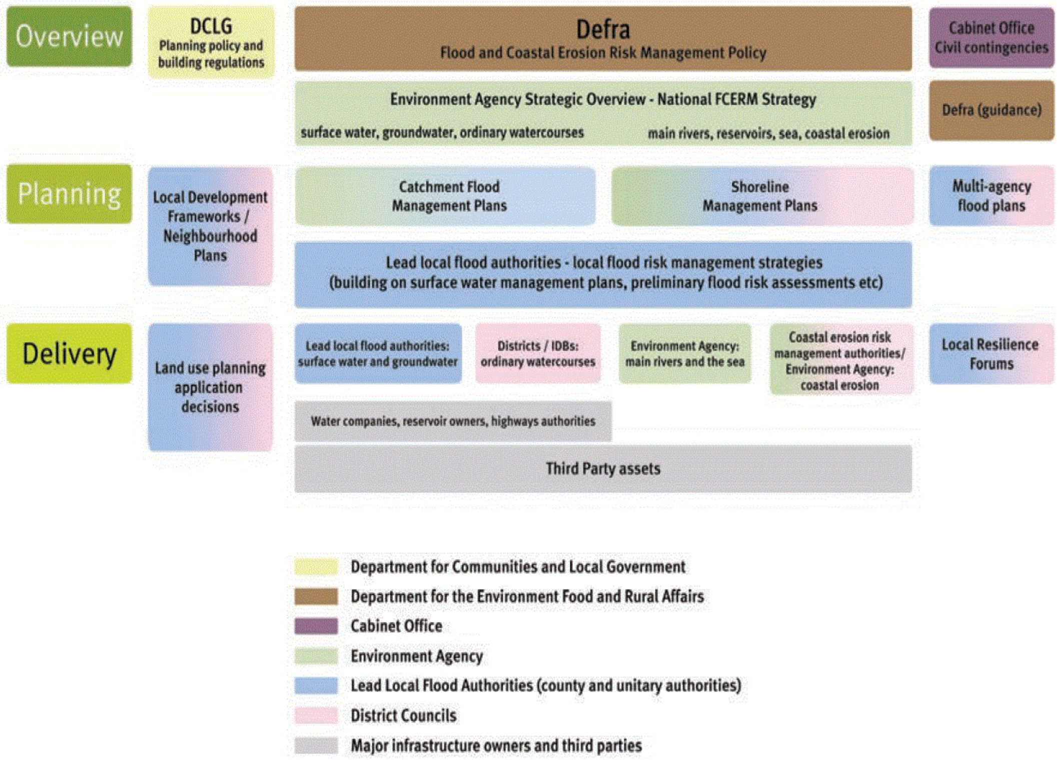

Figure E-2 Governance and responsibilities in England

The National Flood and Coastal Erosion Risk Management Strategy for England provides the overarching framework for future action by all risk management authorities to respond to flooding and coastal erosion in England. The Environment Agency has responsibility for an overview of flood and coastal erosion risk management. To do this successfully, a coordinated approach with other organisations to manage the risk of flooding from all sources is required. The Environment Agency also builds, maintains and operates levees and flood defences.
Local and Regional delivery is carried out by various organisations including Lead Local flood authorities, district councils, internal drainage boards, riparian landowners, water companies, reservoir owners, highways authorities

Regional Flood and Coastal Committees (RFCCs) are committees established by the Environment Agency under the Flood and Water Management Act 2010 that bring together members appointed by Lead Local Flood Authorities (LLFAs) and independent members with relevant experience for 3 purposes:

- to ensure there are coherent plans for identifying, communicating and managing flood and coastal erosion risks across catchments and shorelines
- to promote efficient, targeted and risk-based investment in flood and coastal erosion risk management that optimises value for money and benefits for local communities
- to provide a link between the Environment Agency, LLFAs, other risk management authorities, and other relevant bodies to engender mutual understanding of flood and coastal erosion risks in its area

In England, watercourses are defined as either main river or ordinary watercourses. A main river is a watercourse shown on a main river map. They are usually larger streams and rivers, but can also include smaller rivers. An ordinary watercourse is every river, stream, ditch, drain, cut, dyke, sluice, sewer (other than a public sewer) and passage through which water flows, which does not form a part of any main river.

The Environment Agency, lead local flood authorities (LLFAs) and internal drainage boards (IDB) are named as Risk Management Authorities (RMA) by the Flood and Water Management Act. The Environment Agency manages FCRM assets on main rivers. The local authority, or IDB where it exists, manages assets on ordinary watercourses. Their powers are similar to those the Environment Agency has on main rivers. In nearly all cases these organisations do not have a legal obligation to maintain FCRM assets or construct new assets. However, they do have legal powers (also called permissive powers) allowing them to do work when it is for flood and coastal risk management.

Under common law, the person who owns the land or property next to a river or other watercourse (known as the riparian owner) is responsible for maintaining the flow of water. This means that when the RMA can't justify work, they have to leave it to the riparian owner. Usually, consent is required from the RMA for works by the riparian owner so that the interests of others, such as their neighbours can be protected.

The Environment Agency manages around 45% of the total number of flood risk management assets on main rivers and the coast. Local Authorities, Internal Drainage Boards and individual owners and businesses are responsible for the remaining 55%.

4.5 Guidelines and good practice

For Dams, the Reservoir Safety Register is held by the Environment Agency and is soon to be accessible to all dam owners (some information will remain restricted due to data protection act requirements). Reservoir Safety regulation information is also held. Currently, only the state (the Environment Agency) has access to dam information but owners will soon have access to the database for their dams.

For levees on Main River and the coast the Environment Agency use database called AIMS: Inventory (Asset Information Management System) most of which is available publicly as open data. This includes physical and condition data.
For ordinary watercourse and coastal protection assets, local authorities and IDBs have their own inventories

Good practice documents used include ICE guide to Reservoirs Act, Guide to the application of Eurocode 7 for flood embankments in UK and Ireland.

4.6 Common practices during Levee Life Cycle

The typical construction cost of an embankment varies considerably with impacts on costs including transport distance for fill material, type, and source of material (can be zero in on-site borrow pit), access and time of year of construction. The variation is greatest for very small embankments (less than 2500 m³). For instance, an embankment of following dimensions:

- Height 2m
- Crest Width 3m
- Side slope 1:3

The range in costs per cubic metre is likely to be between £19 to £50 with an average of £33 giving a cost of about £600 k /km (2010 prices)

The Environment Agency carry out detailed visual inspections on all assets on main rivers and the coast that contribute to flood risk management. Inspection includes assets that the Environment Agency maintain and assets that other people maintain. The frequency of inspections is set depending on the risk of assets failing, ranging from six months for the highest risk assets to five years for the lowest risk assets. These visual inspections trigger more detailed assessments as necessary.

The Environment Agency annual maintenance programme includes a range of activities which are carried out according to the timetable specified in the programme. The programme is developed using information from asset inspections and from legal/statutory obligations. This information is used to identify the level of maintenance work required for a specific area.

Figure E-3 Grass cutting at Durranhill Flood embankment, 2011

The Environment Agency consult on the programme with our partners, nongovernment organizations and the public before it is finalized. The agreed programme is made available on the internet.

The Environment Agency and partner organisations work together on planning and preparing for flood events and in carrying out activities during events from flood forecasting, warning, operational response, working with communities and recovery.

4.7 Critical knowledge and data gaps; critical research needs

The following levee- and flood-defence related issues and knowledge gaps are considered to be critical.

- Predicting the current stage in theuseful life of a levee.
- Adaptation and resilience in the future (climate change and other effects). This may link to research on the current stage of asset life in the first bullet point.
- Predicting performance and failure modes especially around transitions in structures
- Impact of climate change on assets, eg wetting/drying cycles, drought effects
- Structural health monitoring – measuring levee performance in near real-time
- Breach initiation and evolution – once failure is initiated how does a breach develop? What are the macro erosion processes and how are the processes governed by the construction material/soils? What is the resulting effect on the breach hydrography and the flood inundation?
- Characterisation of grass types and soils ie what are our levees built of and where? – This could be a problem specific to England or one shared by other countries with historic assets.
- Embracing the circular economy – how can we build and maintain our levees in a more sustainable way of being responsible for waste products and turning them into useful materials?

4.8 Summary of key facts

- 2.4 million properties and a significant amount of critical infrastructure at risk from sea or river flooding (and 3 million more by surface runoff), representing an annual economic consequences of river/coastal flooding risk about 960 million pound (slightly over 1 billion Euro).
- About 8000 km of levees of 1-6 m height, and 22000 hydraulic / flood protection structures

- 70% of them along rivers, another 18% along estuaries and 10 % along the coast
- Safety requirements up to 1/1000yr for large-scale life hazard (depending on cost-benefit), typically 1/100yr or 1/200yr for some life hazard, and 1/5yr - 1/100yr for metrial hazard only.
- Some failures during the winters of 2013/2014 and 2015/2016, due to overtopping and inner slope erosion and along transitions. No lives lost, but some people evacuated. Improvements implemented or under investigation.
- Levees along sea and main rivers managed by state (Environment Agency), the remaining 50% by third (public or private) parties)
- Dam legislation appears to be more restrictive/specific than levee legislation.
- There are central registers for dams, and also for major levees.
- Common practices are annual risk-based maintenance programmes, risk-based inspections every 0.5-5 years (depending on risk) and flood event management. Reinforcement cost is slightly less than 1 Million Euro/km
- Critical knowledge gaps relate to climate change/adaptation, levee performance and failure modes (especially near transitions), predicting life stage of levee and vegetation management.

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5 Finland

Finland is a land of thousand lakes surrounded by vast boreal forests. Indeed, around 10% of its total area comprises water while the country is actually home to more 187,000 lakes and several thousand dams. The Finnish landscape is a pretty flat country as a whole but it´s hilly in the centre and east and there are also mountains area in Lapland.

The flood risk in Finland has many origins. For example, there is a sea risk in the West and South coast respectively in Pori and in Helsinki. There are also spring floods that have a bigger impact on the country when there are warmer temperature and snowmelt.

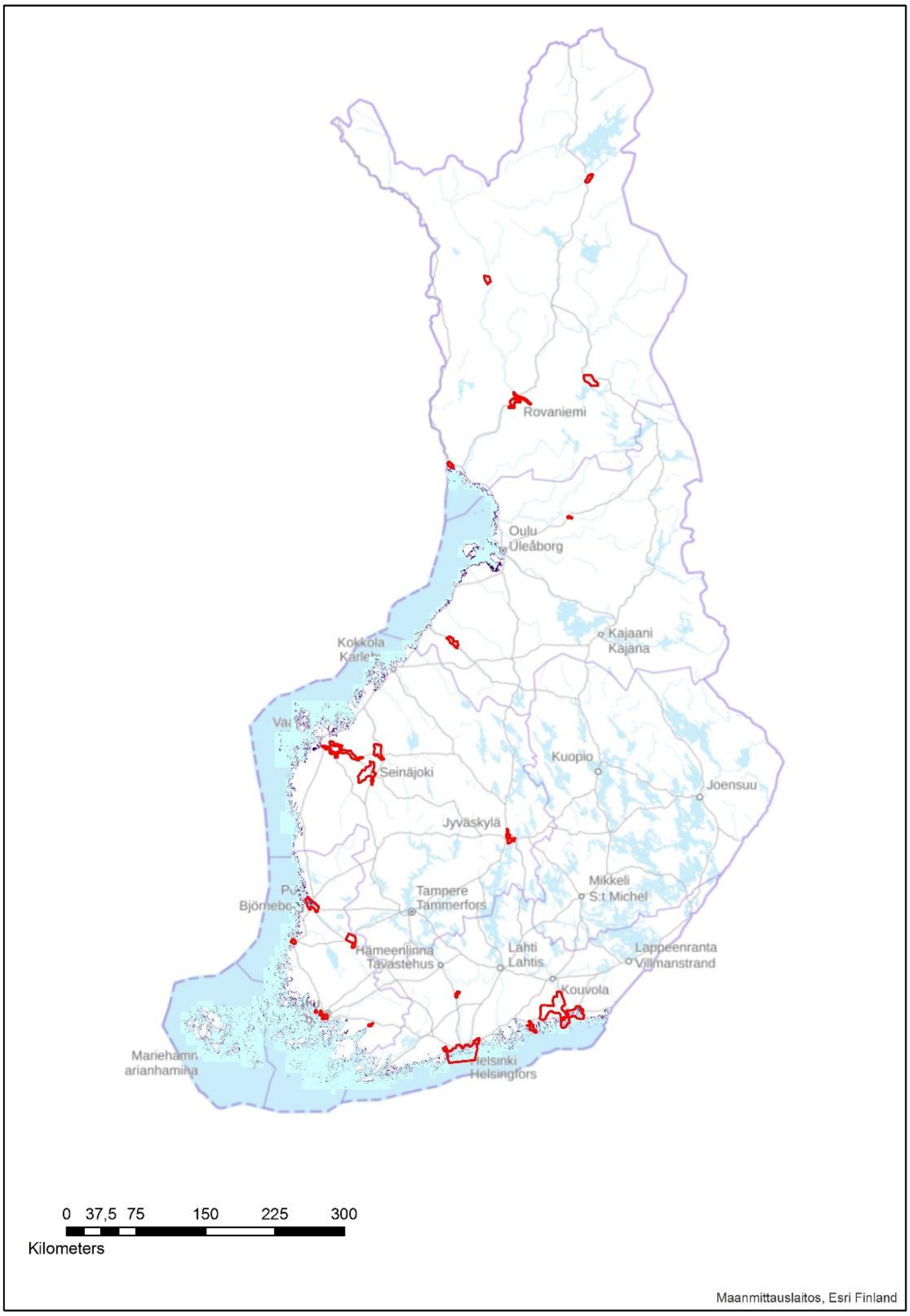

Figure FI-1 : Flood risk areas in Finland (ELY-Keskus)

5.1 Facts and figures on levees and flood defences

There are quite a few levees in Finland. At the present time, there are about 80 levees stored in the data system of the Environmental Administration. This 80 includes 31 levees which comprise 70 km of levees and these have been classified according to the Dam Safety Authority. There are errors in the an amount of non-classified levees because all are not be included.

Most of the levees are embankments that have been built to protect the agriculture. Many of these levees have been built on a soft ground. Embankments are made of clay or silt and they even may be used for agriculture. Because of the structure, embankments may have to be raised (rebuilt) from time to time. Most of these levees are low and a flood with return period rarer than once in 20 years will overtop the embankment.

The revised Dam Safety Act came into force in Finland in 2009. One of the improvement was that flood embankments were defined as dams. Before the revision one levee had already been classified according to the previous Dam Safety Act (1984). Some of the levees are old and in poor condition. New levees have been built in past few years as a result of the European flood directive work.

The most important dam in Finland is a levee. It protects the city of Pori and around 15 000 people living in the hazard area. Most of the levees in Pori have been built in the 1950's and 1970's and for agricultural purposes. The scaling has been pretty low. These levees have been improved since 2008. The levees in Pori are classified as class 1 dam (highest consequence class).

Most levees reduce the risk of the river floods, but some new ones embank sea flood. During the winter time in Finland there is also the risk of frazil ice forming ice jam. This phenomena increases the risk of flooding in rivers.

5.2 Protected value, safety standards and flood risk in Finland

The levee in Pori protects 15 000 people and about 5 000 buildings. These are located in the flood area of 50 km2. There are also other targets in the hazard area, like industry. The economic value is around 3 billion euros. Most of the other levees pose a less danger. There is less than 100 residential buildings in the hazard area.

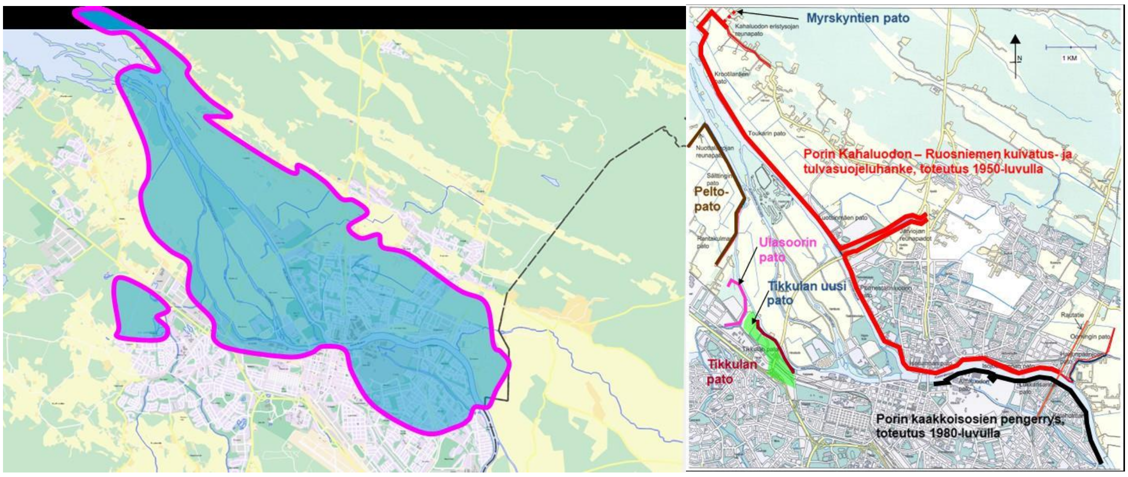

Figure FI-2 : Flooding area (on the left) and flood embankments (on the right) in Pori

At the moment levees are in general built to protect from a flood with the return period of once in 100 years. During the past years many levees have been heightened and improved.

5.3 Recent major floods and (near-)failures of levees

In 2005 the sea level was exceptionally high. The return period of the flood was estimated to be once in 30 years. Many temporary flood defences were built to protect for example the areas near to sea in Helsinki, the capital city of Finland.

River floods are quite common in Finland during the spring time as the snow melts. Very big spring floods have occurred in 1953, 1966, 1984, 2000 and 2018. According to the statistics the highest river flooding occurred in 1807 in Rovaniemi as the river water was 9 meters higher than during a normal summer. The spring flood in 1984 had the return period of once in 30-40 years. It caused many residental buildings to wet and it interrupted the use of an important highway and caused many other things. In 2005 spring flooding in the Lapland cost 4,7 million euros.

Vedenkorkeusennätykset Suomen rannikolla

Asema	Maksimi	Minimi	Havaintoja vuodesta
Kemi	+201 cm (22.9.1982)	-128 cm (14.1.2016)	1922
Oulu	+183 cm (14.1.1984)	-131 cm (14.1.1929)	1922
Raahe	+162 cm (14.1.1984)	-129 cm (4.10.1936)	1922
Pietarsaari	+139 cm (14.1.1984)	-113 cm (4.10.1936)	1922
Vaasa	+144 cm (14.1.1984)	-100 cm (14.1.1929)	1922
Kaskinen	+148 cm (14.1.1984)	-91 cm (31.1.1998)	1926
Mäntyluoto	+132 cm (14.1.1984)	-80 cm (10.4.1934)	1925
Rauma	+123 cm (16.1.2007)	-77 cm (10.4.1934)	1933
Turku	+130 cm (9.1.2005)	-74 cm (10.4.1934)	1922
Föglö	+102 cm (14.1.2007)	-71 cm (10.4.1934)	1923
Hanko	+133 cm (9.1.2005)	-79 cm (28.1.2010)	1887
Helsinki	+151 cm (9.1.2005)	-93 cm (28.1.2010)	1904
Porvoo	+123 cm (6.12.2015)	-69 cm (7.3.2017)	2014
Hamina	+197 cm (9.1.2005)	-116 cm (20.3.2013)	1928

Vedenkorkeutta mittaavien mareografien sijainnit Suomen rannikolla.

Figure FI-3 : Sea water level records (maximum and minimum and the locations in Finland (ilmatieteenlaitos.fi)

The Ministry of Agriculture and Forestry has estimated that extremely rare flooding (once in 250 years) would cost around 550 million euros.

5.4 Legislation and governance

5.4.1 Implementation of EU Regulations

The EU Flood directive has been implemented in Finland by the Flood Risk Management Act (620/2010) 24th July 2010 and Government Decree on Flood Risk Management (659/2010) 7th July 2010. [Both in English in the internet: http://www.finlex.fi/en/laki/kaannokset/2010/en20100659.pdf and http://www.finlex.fi/en/laki/kaannokset/2010/en20100620.pdf]

5.4.2 National legislation

The supervision of dams in Finland is made by the Dam Safety Act (494/2009) and the Government Decree on Dam Safety (319/2010). [Both in English: http://www.finlex.fi/en/laki/kaannokset/2009/en20090494.pdf and http://www.finlex.fi/en/laki/kaannokset/2010/en20100319.pdf] The Dam Safety Act defines that “dam means a structure such as a wall or embankment the purpose of which it is to permanently or temporarily prevent the spread of a liquid or substance that behaves like a liquid impounded by the dam or to regulate the surface level of the impounded substance;” and “flood embankment means a structure the purpose of which is to prevent the spread of water at times when the water level of a watercourse or sea level is unusually high". Therefore flood embankments are dams and if a flood embankment in the event of an accident may cause any danger it has to be classified by the Dam Safety Act. The dam safety authority (the ELY Centre for Kainuu) supervises dams and levees, if they pose a danger.

The Flood Risk Management Act Section 10 defines Flood risk management plans which has to be prepared for river basins with one or several designated significant flood risk areas and a significant flood risk area in the coastal area. These flood risk management plans are ready and approved by the Ministry of Agriculture and Forestry. These plans are the reason for the construction of some new levees.

5.4.3 Governance

The Centre for Economic Development, Transport and the Environment (ELY Centres) (Häme, Kainuu and Lapland) act as the regional dam safety authority which is appointed by the Ministry of Agriculture and Forestry.

If the levee is classified by the Dam Safety Act, the dam safety authority (the ELY Centre for Kainuu) is responsible for the supervision of the dam. Dam (levee) owner is a person or legal entity registered with the dam safety authority, who is responsible for the design, construction, operation and maintenance of the dam.

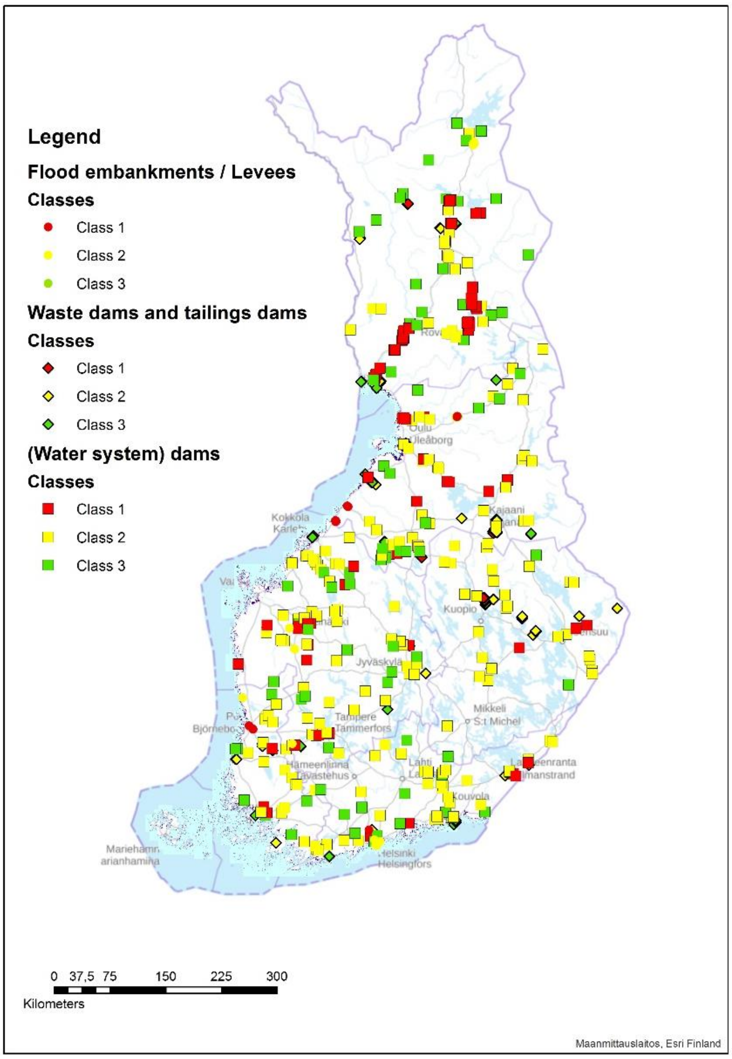

Figure FI-4 : Dams and levees classes in Finland (ELY-Keskus)

Dam and levees classes:

- Class 1 dam/levee
A class 1 dam/levee is a dam/levee which in the event of an accident causes danger to human life and health or consider danger to the environment or property. Class 1 is always confirmed by hazard analysis. New class 1 dams are designed for a flood return period of 5 000 – 10 000 years.

- Class 2 dam/levee
Class 2 dam/levee, which in the case of an event may constitute a danger to health or greater than minor danger to the environment or property. For class 2, new dams are designed for a flood return period of 500 – 1 000 years.

- Class 3 dam/levee
A class 3 dam is a dam which in the case of an event causes minor damage to the environment or property. It cannot endanger human life or health. Class 3 dams are designed for a flood return period of 100 – 500 years.

Hydrological dimensioning of a flood embankment is specified according to the need for the flood protection.

If the levee is not classified, the owner is responsible for the design, construction, operation and maintenance of the dam, but there is not any real supervision.

The owners of the levees vary. New ones that have been built after the flood directive usually belong to municipalities and towns. There are some flood embankments which has been built at the same time as a hydropower station and these may belong to the hydropower company. Many embankments have been built to protect farming land by the river. There may belong for example private society. Afterwards there might have been construction works and these same embankments might be protecting houses.Roles & responsibilities are set out in National Strategy.

5.5 Guidelines and good practices

- The Dam Safety Act http://www.finlex.fi/en/laki/kaannokset/2009/en20090494.pdf
- The Government Decree on Dam Safety
  http://www.finlex.fi/en/laki/kaannokset/2010/en20100319.pdf
- The Dam Safety Guide
  http://www.environment.fi/en-US/Waters/Use_of_water_resources/Dams_and_dam_safety/Dam_Safety_Guide

There is a Dam Safety Act and Decree in Finland. The Dam Safety Guide is made to complement and elucidate the law and the decree through examples and descriptions

5.6 Common practices during Levee Life Cycle

The design practices of levees are close to those of embankment dams. For example in Pori, the dams have been repaired or rebuilt as a kind of zoned earthfill dams with underdrain or drainage ditch. A service road is provided when possible. The cost of the repair works is around 500 – 1 000 € / m. Building a new levee is about 500 € / m.

Flood embankments are classified according to the dam safety act if an event or an accident is likely to cause danger to human life and health or danger to the environment or property. According to the act, a monitoring program must be prepared to classified dams and embankments. It consists of continuous monitoring as well as annual and periodic inspections in such a way that every factor affecting dam safety is subject to monitoring and inspection.

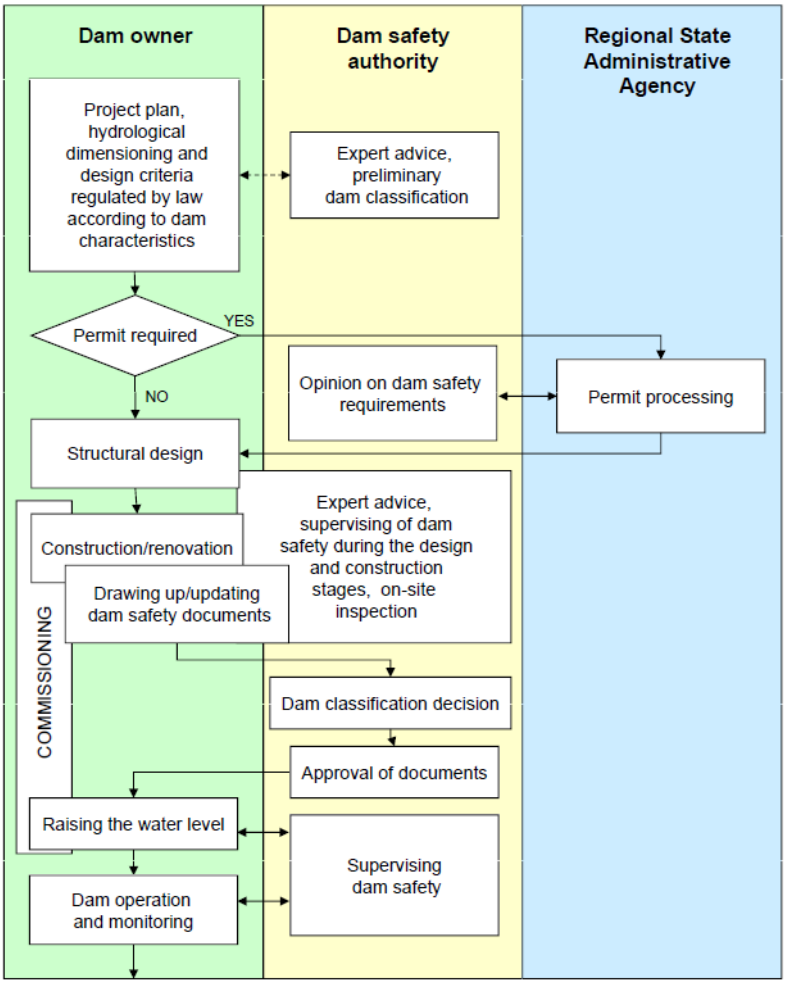

Figure FI-5 : Procedure for construction or major renovation of dams and levees

Maintenance:
The owner of dam (embankments) must prepare and regular update a plan of measures in case of accidents and disturbances concerning a class 1 dam. This action plan constitutes the dam owner's own emergency preparedness.

The emergency planning for dam and levees accidents and rescue operations are the responsibility of the rescue authorities. However, the owner of a dam and levees must present measures to be taken.

- To prevent accidents in case of disturbances as well as to to prevent and limit damages at the dam
- To protect humans, property and the environment against damage
- To report an accident

Inspection of levees:
In addition, periodic inspections must be arranged every five years where dam safety authority and rescue authority has the right to participate. If flood embankments are not classified they are hopefully inspected at least once a year before the floods.

During an inspection of levees, technical information concerning levees must be checked and also the levees classification.

5.7 Critical knowledge and data gaps; critical research needs

In some (older) cases levees have been built with very little real knowledge and with improper work. Difficulties might develop by frost, small animals (which dig holes), depression, and tree roots.

5.8 Summary of key facts

- About 80 registered levees
- 31 levees have been classified according to the Dam Safety Act, which is equivalent to 70 km of classified levees.
- Most levees protect farm land from rivers, also some sea levees and urban levees
- The most important levee (at Pori) protects 15000 people and 3 million Euro in assets
- Many levees are now being constructed or improved in response to the EU Floods Directive, safety standards are also upgraded to typically 1/100 yr.
- Damage potential for a 1/250 yr flood would be about 550 mln Euro
- Large (springtime/snow-melt) river floods in 1953, 1966, 1984 and 2000 with up to 5 million Euro damage; large (1/30 yr) storm surge in Helsinki in 2005.
- Dams and levees have common legislation/regulation

5.9 References

https://www.pori.fi/asuminen-ja-ymparisto/ymparisto/tulvasuojelu/tulvavaara

- The Dam Safety Act (494/2009) http://www.finlex.fi/en/laki/kaannokset/2009/en20090494.pdf (unofficial translation)
- The Government Decree on Dam Safety (319/2010) http://www.finlex.fi/en/laki/kaannokset/2010/en20100319.pdf (unofficial translation)
- The Dam Safety Guide, http://www.environment.fi/en-US/Waters/Use_of_water_resources/Dams_and_dam_safety/Dam_Safety_Guide

6 France

6.1 Facts and figures on French levees and flood defences

In France, two main families of hydraulic structures help ensure flood protection:

- levees and similar structures whose purpose is to prevent water (from the sea, a river, a lake or a torrent) to flood a so called "protected" area,
- flood retention dams whose purpose is to store flood water and lower the flood peak discharge, usually found only on rivers; some of them have one or more functions other than flood retention.

Also, some diversion canals can be found, whose function is to divert a part of a river flood flow to another area which can be a pond or lake, the sea, or a flood retention area or basin.

Flood retention areas can be natural (unprotected land) or artificial. In the latter case they result from the existence of a dam or basin (in this case the flood in the storage area can be higher than the natural flood in terms of water level) or of a levee system (in this case the flood risk in the area is generally reduced from natural flood risk in terms of frequency and/or water level and velocity).

There are no major, moveable storm surge barriers, except some harbour locks.

There are about 9000 km of levees in France, about 8000 km of inland levees (rivers, lakes, torrents) and 1000 km of marine levees[1] (sea, estuaries), these figures include multipurpose structures. These figures concern mainly the first line of defence, and no secondary line of defence or indirect protection structures like groynes, breakwaters or river weirs. Levees height range up to 6 meters high with possible local exceptions higher than this.


A fluvial levee near Orléans


A coastal levee near les Saintes-Maries-de-la-Mer


A torrent levee in Domène

Figure F-1 : Levees in France

According to their size, there are thousands or tens of thousands of dams, probably thousands of flood retention dams, most of them being small or multifunctional. France's highest dam, Serre-Ponçon has among other roles, flood retention, and is 124 m high for a reservoir volume of 1.3 km^3. The smallest flood retention dams only have a few meters high and thousands of m^3, they can be built on temporary or permanent rivers, but also sometimes on "dry" thalwegs.

Flood protection levees are usually made from earth material, but there are some other types of dikes (flood walls, "hard" structures, "mixed" structures made partially from earth and "hard" material). Most of the levees are built from local material, with a long and complex history and are globally

[1] Recent data shows that almost 2900 km of the French metropolitan coast has been affected by coastal development

heterogeneous (see ILH section 3.3.3) and poorly known in detail, apart from levees which have been recently rebuilt or reinforced. River levee material is generally silty or clayish, while sea levees material is often made of a sandy and silty core and covered with rocks or hard protection structure or in other cases made from very fine material from local swamp sludge.

Levee based protection systems often include structures which are multifunctional, as many structures whose main vocation is not flood protection actually have this role. They can be linear transport infrastructures (roads, railways, navigation canals) or other types of structures (harbour infrastructure, buildings etc.).
Protection systems can also include natural features like dunes, rocky high ground etc.
Protection systems also include many types of "annex" hydraulic structures, like sluices, gates, culverts, pumping stations etc.
There are no or very few (or maybe less identified) temporary protection like temporary raising structures or flood walls, except common gates closed during flood.

Regular maintenance is generally planned in advance, or it can be decided as a result of an inspection which detects some repairs to be done. Major repairs need to be decided and defined after a complete assessment, including a diagnosis of the causes of the (eventually potential) problem(s). Typical reinforcement works cost in a range of 1-2 Million €/km.
The cost of protection against fluvial flood in France was subject to a recent cost analysis (*Cerema, 2014. Coût des protections contre les inondations fluviales, ed, Connaissances. Cerema, Bron.*). Among the major levee management organizations, the ranges of the main costs are the following:

- investment (studies and levee reinforcements) on the period 2007-2013: 4 M€ for the 530 km of State levees on the Loire River to 20.65 M€ for 200 km of levees managed by SYMADREM on the Rhône River;
- maintenance: 4 400 to 8 500 €/km/y;
- management: 2 000 to 3 800 €/km/y.

Examples for different levee and flood defense management organizations:

- SYMADREM, the levee management organization for the south of the Rhône River and sea along the Rhône delta, spends 10 000 €/km each year for levee inspection and maintenance and management of the office. It usually spends 2.5 € million/km for 4/5m high levee reinforcement (Demolition of the old levee and reconstruction of a new structure with all the required structural functions), twice this amount for an overflowing resistant levee, and 1 € million more per kilometre if the structure requires bank protection. It also spends 1.6 € million for its first regulatory levee system risk analysis survey (74 km of levees), half of this cost corresponding to geotechnical studies, and the survey's update (every 10 years) being estimated at 0.5 € million.
- For the 530 km of levees managed by the State on the Loire River and the Allier River, the annual management expenditure is about 4.5 € million. Approximately half of this amount corresponds to the remuneration of 40 FTEs with missions that go beyond the management of levees (river bed maintenance, navigation Police etc.), a major part for the management of the operating centres and about 800 000 € of annual maintenance expenditure. The annual investment expenditure is about 5 € million.
- Seine Grands Lacs is an organization managing 391.5 km of flood retention dams and four associated retention lacks upstream of rivers Seine, Marne, Aube and Yonne, for a total storage capacity of up to 800 million cubic metres. These flood retention dams prevent inundation for an urban area covering up to 10,000 hectares. In 2015, Seine Grands Lacs, which has 130 employees, spends 12.7 € million for operation activities and 13.3 € million for investment.
- Chambéry Métropole, in the French Alps, manages 17 km of levees. A full time technician and about 500 h of engineer time are required for levee management. The annual vegetation management expenditure is about 9 000 € and the average cost for emergency repairs is about 20 000 € a year. Chambéry Métropole also pays 7 500 € each year for a flood announcement system. In 2016,

regulatory levee system risk analysis survey (updated every 15 years) and regulatory levee assessment studies (updated every 5 years) have been completed for a total amount of 400 000 €.

6.2 Protected value, safety standards and flood risk in France

The stakes of flood risk

An estimation has been made by an official group representing the insurance companies on the annual cost of major floods, it gives a total of 200 to 300 M € for insured damage and 1 to 1.4 billion € for all damage. This is for both protected and unprotected areas, based on present situation of the protection system. From 12 to 20% of this damage relates to maritime events, this percentage is expected to raise, given the higher hazard due to climate change, and the increase of urbanisation close to the seas.
Another 2016 study (*Les catastrophes naturelles en france – Bilan 1982-2016 – publication CCR)* finds an average annual loss of 533 million euros for floods in the period 1989 – 2014.
All in all:

- 17.1 million people live in river flood hazard areas, which represents 5% of the national surface, with 9 million jobs located in it.
- 1.4 million people live in sea flood hazard areas, with 850000 jobs located in them.
- The major flood protection systems "protects" about 20000 km^2 and about 2M people.

Safety standards

The "modern" approach to safety standards is to make a distinction between the protection level (the water level up to which the protected area is not flooded), and the safety level (the water level up to which the chance of the levee breaching is insignificant, by any mechanism). A danger level can also be defined. It corresponds to the water level beyond which the chance of the levee breaching is probable, by any mechanism. The protection level is related to the main hydraulic function, the safety and danger levels are related to a structural performance. Figure F-1 presents these levels on a levee resistant to overtopping because of the existence of a spillway (or segment resistant to overflowing). Finally, a level of security of people can be estimated. It corresponds to the level of water in the water environment, in contact with the system, up to which no person in the protected area is in danger.

These loading conditions can be objectives, in the case of a project or where the objectives have been previously specified by the authority responsible for the levee. They also can be findings of the assessment or risk analysis process. These levels can be expressed either in probability of the loading event and/or in terms of altimetry. Equivalence between the altimetric levels and the probability of the loading event is a complicated matter as different events (or combination of events) can lead to the same altimetric level.

Since 2017, the national legislation asks for levee systems protection level to be under or equal to a loading condition (a water level) equivalent to a 5% breaching probability. This legislation also asks to estimate flood risk for breach scenarios which result from a danger level overrun, with a danger level at least equivalent to a 50% breaching probability.

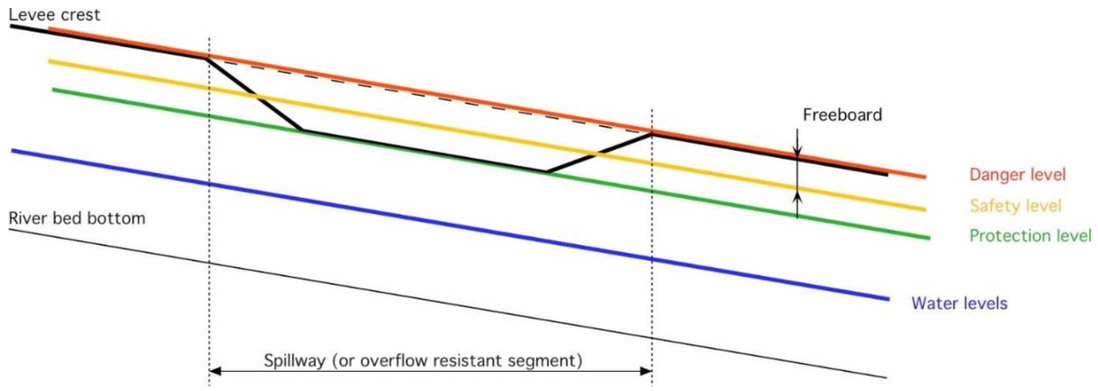

Figure F-2: Levee sytems related loading levels: protection level, safety level and danger level along a fluvial system resilient to overtopping because of a spillway (source: Rémy Tourment)

Old levees can have their crest higher than their safety level (a rough estimation gives a rate of one out of three), as shown of Fig F-2. Furthermore, the higher the crest level, the greater the consequences may be in the case of a breach before this level.

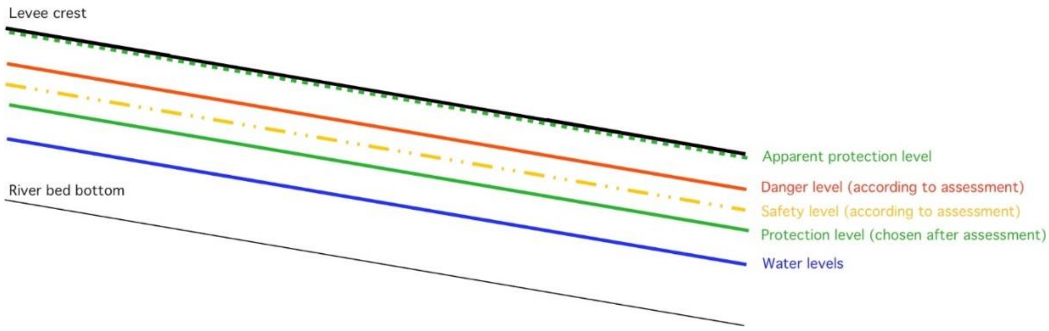

Figure F-3: Levee sytems related loading levels: protection level, safety level and danger level along an old fluvial system not resilient to overtopping and with a low safety level (source: Rémy Tourment)

The optimum situation is to have a safety margin above the protection level, so the protected area can be flooded above this limit, in a controlled way, without breaching. Systems such as these have resiliency to overtopping/overflowing, either because of existence of a spillway or because of some physical resistance to overtopping/overflowing in the lower sections, for instance because of a revetment.

There is NO standard for flood protection level, which is up to the local stakeholders to set. Typical flood protection level usually ranges from 1/5 to 1/10 years in agricultural areas and from 1/20 to 1/100 years in populated areas. An upgraded and resilient system currently in project in the south of the Rhone River will protect against floods up to 10^{-2} annual probability and will be able to withstand floods up to 10^{-3} annual probability without damage. The annual probability of failure (integrating nine representative floods) for new levees is inferior to 10^{-4}.

Actual safety level of existing levees
There is also no standard for the safety level of levees. Engineering rules apply to levees for design or regular verification and justification. French COLD, CFBR, publishes guidance on how to conduct such calculations, but there is no set value for the safety level, which is, like the protection level, left to the appreciation of the local stakeholders.

Residual risk
This concept, as it is phrased in Appendix B of this report, does not really relate to the French situation and way to analyse flood risk and levee situation since:

1. there are many areas which are subject to flood risk but not protected by structures.
2. in protected areas, we should know, because of regulatory Hazard Studies (études de dangers) what is the actual residual flood risk, due to water level being higher than the protection level OR because of levee safety level and associated potential failure. But these have not been conducted in all systems at the present moment, consequently we don't have a national synthetic situation.

6.3 Recent major floods and (near-) failures of levees in France

France did not have any major and recorded flood defence failure since the 19th century, until the winter 1993-94, when two floods from Rhone river caused multiple breaches in the levees and flooded the Camargue delta. Since this episode, France has been marked by other dramatic events revealing the potential fragility of certain river and sea levees and reminding the society the necessity to take proper care of existing flood defences.

These recent major events include:

- floods of the Camargue river of 1993-1994: multiple breaches and other disorders on levees of the downstream Rhone river. They caused the flooding of the Camargue island (12,500 hectares and 450 houses affected), causing many damages including the death of livestock;
- 1999 flood of the Aude river: breaches in the commune of Cuxac. Flooded housing under 2 m of water, several hundred houses flooded, 5 victims (a total of 25 victims in the department and 35 in the region, not all linked to levees);
- floods of the Agly river of 1999, 2013 and 2014: numerous disorders and several breaches are identified on levees. The resulting flooding causes significant material damage;
- flood of the Gard and Rhône rivers in 2002: breaches in Aramon and Comps in the Gard department result in the flooding of inhabited areas, causing numerous victims and considerable damage (damage = 1 billion of euros) ;
- flood of the Rhone river in 2003: breaches caused the flooding on the left bank (north of Arles) and the right bank (Camargue Gardoise from the south of Fourques to the sea) of the Rhone river and cause about one billion euros damage in the Rhone delta area;
- Xynthia event of 2010: the combination of strong winds and strong tides gave rise to a storm surge and a marine submersion causing severe flooding in some coastal regions (mainly Charente-Maritime and Vendée). The consequences are very important: 49 deaths, 2.5 billion euros in direct damage and 200 km of levees to be rebuilt;
- heavy rainfall and floods in May 2016: significant floods on numerous rivers (mainly on the Seine river, the Loing river and on the Cher river and its tributaries). Numerous disorders and breaches are recorded on canals and small dams. Levees of the watercourses concerned are only weakly solicited and only minor disorders are identified.

In France, history shows that each river major flood or sea extreme event conducts to levee deteriorations or levee breaches. Levee breaches result from failure scenarios involving chains of physical mechanisms. These mechanisms can be classified in three main families: internal erosion mechanisms, external erosion mechanisms and instability mechanisms. In France, according to experts and levee managers experience (there is no significant statistics about levee breaching causes), levee breach scenarios are most of the time initiated by internal erosion mechanisms (about half of levee breaches) and by overflowing external erosion mechanisms (about half of levee breaches). Breaching scenarios are much less initiated by other kinds of external erosion mechanisms and instability mechanisms, although these can cause major damage to the levees, but can be repaired after the loading event.

6.4 Legislation and governance in France

6.4.1 Implementation of EU Regulations

The global French flood prevention policy

The European Flood Directive has been implemented in France, with no direct link with the levees (or other types of flood defences) management or levee related regulation. Levees are taken into account in the general appreciation of the flood risk, but not in detail for this first implementation.

The first national flood risk management strategy adopted October 7, 2014 is part of the strengthening of the national flood risk management initiated within the framework of the implementation of the EU Floods Directive. The preliminary assessment of flood risks (évaluation préliminaire des risques d’inondation, EPRI) conducted by the State in 2012, across the country, found that nearly 1 out of 4 French citizens and 1 of 3 jobs are potentially exposed today. Given this situation, and under the impulse of the flood directive, France has mobilized considerable human, technical and financial

resources to strengthen its policy of managing the various risks of flooding from marine submersion, overflow of rivers (river as torrential), slick ascent, urban or agricultural runoff.
Thus for the first time, France has a policy that requires a proactive approach to flood prevention across all risk areas: the aim of this policy is to pay particular attention to sectors most exposed: significant risk flood areas (territoires à risque important d'inondation, TRI), but also to areas unaffected by floods in recent decades.
Beyond the involvement of all territories, and through this strategy, the Government recalls that everyone has a role to play from the risk of flooding: citizens, businesses, local and the state must adapt their behaviour. To better protect themselves, it is essential to participate and to better understand the risks to which it is exposed.
Following a national consultation with the public, the national flood risk management strategy, which was established by the Ministers of Ecology, aims to ensure the coherence of actions in the territory.
The national strategy sets three main objectives:

- increase the security of populations
- reduce the cost of damage
- greatly shorten the time to return to normal in disaster areas.

Associated funding tools
The collective and concerted development of this strategy of flood risk management in the Flood Joint Commission (Commission mixte inondation, CMI), led to a text shared by both the State and the stakeholders. This strategy responds to the high expectations of all stakeholders, including local authorities, of a shared framework to guide the national flood risk management policy.
Set up exactly one year after the transposition of the European Directive on floods as a national commitment into the environmental law of July 12, 2010, the CMI embodies the shared governance between the government and stakeholders needed to reform the national flood risk management policy. This reform is being written today in the national risk management strategy (stratégie nationale de gestion des risques, SNGRI) whose development is closely monitored by the CMI.
Through the affirmation of the main strategic guidelines, the CMI works, in fact since 2011, to change the policy of prevention to risk management objectives based on the prioritization of territories and fields of action. In support of its work, the CMI puts directly into practice these strategic principles by examining and labelling Flood Prevention Action Programmes (Programmes d'Actions de Prévention des Inondations, PAPI) and Rapid Submersion Plan (Plan de Submersion Rapide, PSR), and by supporting major river basins in the establishment of their flood risk management plan (plan de gestion des risques d'inondation, PGRI) accompanied by local strategies. Many of these PAPIs and PSRs involve flood protection works. PSRs aim notably the reinforcement of 1 200 km of levees. In 2014 and since 2011, these funds had distributed 970 € million used for the renewal of more than 335 km of levees.
PSRs are endowed by the French State, over six years, with a grant of € 500 million from the fund for the prevention of major natural hazards (Fonds de Prévention des Risques Naturels Majeurs, FPRNM), in addition to local public funding. These funds are in line with those of PAPIs, which have been committed with € 350 million over the same period.
At the beginning of 2017 and since 2011, 133 PAPIs and PSRs totalised € 1,680 million of investments, whose € 658 million are granted by State. Among these projects, 41 concern the prevention of marine submersion (29 PAPI and 12 PSR), which includes 486 € million of investments and 264 km of flood protection works.

River Plans (Plans Fleuves) complete the tools solutions to help flood protection managers and finance their activities. The implementation of the river plans dates from January 4, 1994, with the announcement of the Plan Loire Grandeur Nature by Michel Barnier, Minister of the Environment, to prevent Loire floods. It has been followed by the Plan Rhône in 2005. These plans seek to give territorial coherence and an inscription of the policy of the river in a spatial planning process. They aim to build coherent approaches for natural and landscapes heritage, economic development, and flood prevention.

6.4.2 National legislation

The same regulation relates to dams, levees, and other protective structures, and has for objective the safety of the structures and the security of the population who can be at risk in the case of their failure. Dams are classified according to their height and the volume they can contain; flood protection structures are classified according to their height and the population they protect.
The first version of this regulation (which includes various texts), is based on a decree of December 11, 2007, (with dams and levees classified in 4 classes (A to D) by State services. This regulation has been adapted with a decree of May 12, 2015. Now, both dams and levees are declared to State services and classified in three classes (A to C) by managers, the smaller structures having no obligation. Regarding flood defence structures, this new regulation, which focuses on flood protection and not only on structures safety, applies to levee systems (and not only to levee segments) and to flood retention dams.
According to the class of a structure, the responsible organisation (owner for a dam, manager for a levee) has to fulfill some obligations:

- maintaining an archive of all documents related to the structure (administrative and technical: design, assessments, works, events, etc.),
- keeping a day-to-day register of all events (dams only in 2007 regulation, and levees also in 2015),
- having written instructions for operation and maintenance, including a special section on operation during flood events,
- conducting and reporting detailed regular inspections (periodicity depends on the class),
- preparing a report on the operation, maintenance and incidents (obligation and periodicity depend on the class),
- conducting and reporting a monitoring analysis (dams only, obligation and periodicity depend on the class),
- initial safety assessment (only for levees),
- regular complete assessment and risk analysis (obligation and periodicity depend on the class),
- information to the State authorities in case of incident or accident,
- submitting major work projects for Class A dams and levees and risk analysis of levee systems of Class A to the opinion of the Standing Technical Committee on Dams and Hydraulic Structures.

Engineering companies have to be accredited by the Ministry of the environment, based on references.

6.4.3 Governance

The State (Ministry of Environment) is in charge of regulation, and its local services are in charge of controlling the regulation is applied by the owner or manager. Usually, dams have only one owner, so it's the owner’s responsibility to apply the regulation. Most of the levees, and furthermore levee systems, have many owners so the responsibility of applying the regulation falls to the manager (which does not absolve the owners from any responsibility in case of a problem). The safety of the population is an attribution of the Mayor of the commune and of the county Prefect (Préfet de département).

Until December 31, 2017, levee management organisation were of various types (private: people, associations or companies, public: State, local authorities, association of local authorities, public institutions or companies etc.).
New laws (n° 2014-58 of January 27, 2014 and n° 2015-991 of August 7, 2015) define the Management of aquatic environments and flood prevention (GEMAPI: gestion des milieux aquatiques et prévention des inondations) as a scope entrusted to intercommunal level (cities, urban communities), from January 1, 2018. Following the law n°2017-1838 of December 30, 2017, French Departments and Regions already in charge of management of aquatic environments or flood prevention can keep their responsibility, in agreement with intercommunal or communal level. This assignment will supersede the existing actions of local authorities and their groupings, actions that were previously optional and not uniformly present in the territory at risk of river flood or marine submersion. It will allow

intercommunal level to collect specific taxes to support the funding of the activities related to the flood prevention. Funding for levee management may also result from subventions from State Agencies, Regions, Counties, or Municipalities (for investment only, and not for operation activities).

Except if they are themselves accredited by the Ministry of environment, levee managers must employ accredited consulting engineering companies to conduct levee safety regulatory studies and to design new protection structures.
Figure F-4 presents actors and relations in the field of levees, for the 2007 regulation model.

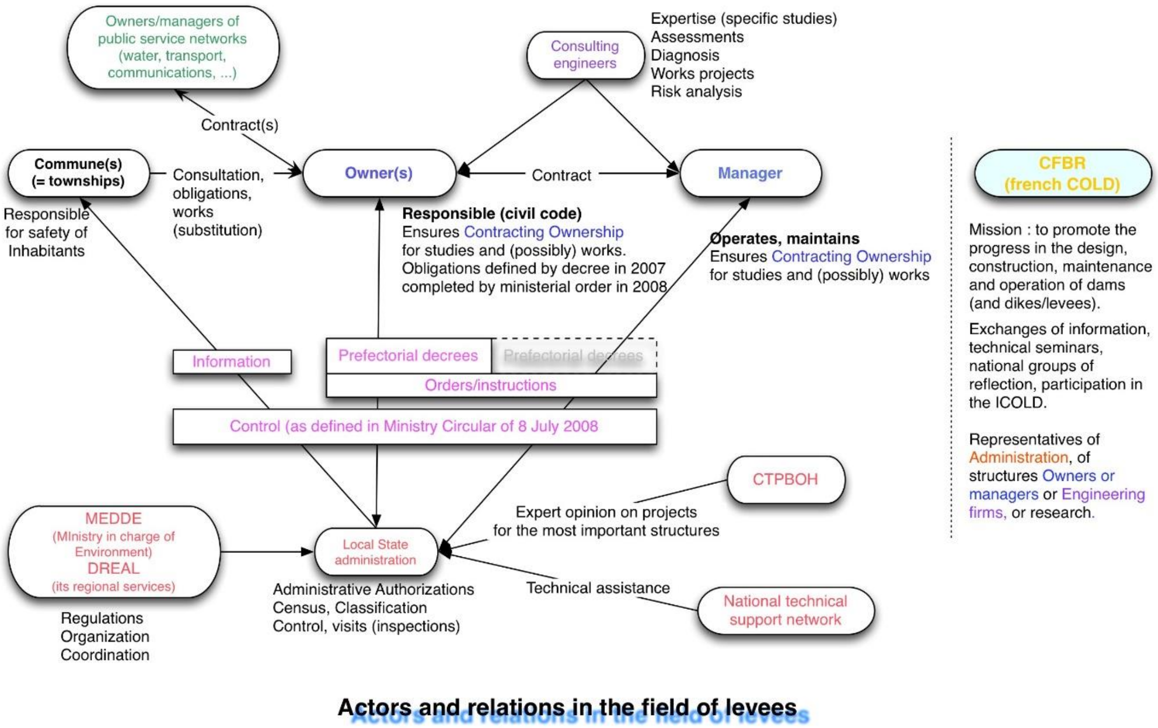

Figure F-4: Actors and relations in the field of levees, for the 2007 regulation model (source: Rémy Tourment)

6.5 Guidelines and good practices

The French Ministry of Environment has sponsored a "Technical reference manual for sea and river levees". The purpose of this document is to provide a common technical basis for mutual understanding of the actors in the field (protection structures managers, state services, engineering offices, other flood risk managers, local authorities and land use managers) during their communications; it is not a regulatory document nor prescriptive. The presented concepts and principles are for the purpose of clarification and sharing of vocabulary and even some methods.

There are no specific guidance documents for the design of levees. CFBR issues general guidance documents which can be applied to both dams and levees, with some specificities when needed, including "Guidelines for the justification of embankment dams and levees".

These different documents (“Technical reference manual for sea and river levees” and CFBR documents) can be downloaded on the CFBR website: http://www.barrages-cfbr.eu/Recommandations.html.

The ILH is used by some of the profession, but because of the language this is not general. A translation of the ILH in French language is going on (http://www.eau-mer-fleuves.cerema.fr/international-levee-handbook-un-guide-sur-les-a1147.html).

In terms of guidance for assessment, investigation, inspection and management, Cemagref (now Irstea) published the following handbooks, which are used as reference by many members of the levees community (managers, engineers etc.):

- Lino et al., 2000, Méthodologie de diagnostic des digues appliqués aux levees de la Loire moyenne
- Mériaux et al., 2004, Surveillance, entretien et diagnostic des digues de protection contre les inondations : Guide pratique à l'usage des propriétaires et des gestionnaires, (an English version can be ordered here: http://www.quae.com/fr/r141-surveillance-maintenance-and-diagnosis.html)
- Fauchard C., Mériaux P., Méthodes géophysiques et géotechniques pour le diagnostic des digues de protection contre les crues (an English version can be ordered here: http://www.quae.com/fr/r135-geophysical-and-geotechnical-methods-for-diagnosing-flood-protection-dikes.html)
- Vennetier M., Mériaux P., Zanetti C.,2015, Gestion de la végétation des ouvrages hydrauliques en remblai: http://www.irstea.fr/nos-editions/guides-techniques/guide-vegetation-digues

For the coastal levee inspection and management, former CETMEF (now part of the Cerema, a public establishment linked to the Ministry of Environnement) published several guidance that are still relevant:

- Cerema, 2016. Étude des systèmes de protection contre les submersions marines - Méthodologie et études de cas issues du retour d'expérience Xynthia. References, Cerema, Bron, 446 p.
- Cerema, 2015. Analyse du fonctionnement hydro-sédimentaire du littoral - Cahier technique, Connaissances. Cerema, Bron, 76 p.
- CIRIA, CUR, CETMEF, 2009. Guide Enrochement - L'utilisation des enrochements dans les ouvrages hydrauliques - Version française du Rock Manual (2e édition). CETMEF, Compiègne. (http://www.eau-mer-fleuves.cerema.fr/guide-enrochement-l-utilisation-des-enrochements-a407.html)
- CETMEF, 2008. Pathologies des ouvrages portuaires : méthodes d'investigation (No. Notice n° P 08-02), Etat de l'Art, technique portuaire. Compiègne.
- CETMEF, 2002. Surveillance, auscultation et entretien des ouvrages maritimes - Fascicule 4 : digues à talus et digues mixtes.
- CETMEF, 1998. Recommandations pour la conception et la réalisation des aménagements de défense du littoral contre l'action de la mer (No. ER PM 98.01), Etat de l'art, Aménagement Côtiers. Compiègne.
- CETMEF, 1997. Conception et dimensionnement des digues à talus (No. PM 97.01), Etat de l'art, Aménagement Côtiers. Compiègne.
- CETMEF, 1994. Surveillance, auscultation et entretien des ouvrages maritimes. Fascicule 1 : Ouvrages en maçonnerie, Etat de l'art, Aménagement côtiers. Compiègne.

The outputs from the FloodProBE EU project Work Package 3 are also used, regarding geophysics and use of LIDAR (http://www.floodprobe.eu/project-outputs.asp).

6.6 Common practices during Levee Life Cycle

Inspections performed by the levee management in France:

- Complete initial inspection. This inspection is needed in order to initialise the knowledge about the levee. Part of the initial assessment. Helps as a reference for future inspections, up to the next complete inspection.
- Operational inspections by levee guards.
- Detailed inspections performed by engineers, either part of the manager staff or hired contractors. Frequency can vary between 3 and 6 years based on the magnitude of the protected population.

- Complete inspections including hidden parts (underwater and inside pipes) performed by engineers, possibly including specialists, either part of the managerial staff or hired contractors. It helps as a reference for future inspections, up to the next complete inspection. It is a part of the periodic safety review process and must be done at the same time as this one: every 10 years for Class A levee systems, every 15 years for Class B levee systems and every 20 years for Class C levee systems.
- Pre-Flood inspections are not required, but useful.
- During flood inspections are performed by the levee manager, possibly with help from local authorities and levee owners.
- Post-flood inspections are required, and can be a good source of information not normally available (i.e., seepage, closure integrity).
- Special inspections as part of a specific assessment, triggered because of a special event (accident, seismic), because of planned works, or other specific reason.

Figure F-5: initial inspection on an estuarine levee in Gironde (source: Rémy Tourment)

Levee control authority inspections performed by the French State authorities:

- Initial inspections. In France the control of levees by the State is quite recent and many levee systems are yet to be inspected for the first time. During the initial inspection, the control authority has to obtain all pertinent information about the levee and its management, and check the safety of the levee through the level of knowledge and organization of the levee manager and the result of its own assessments.
- Periodic inspections. For class A, B & C levees (period varying from 1 to 10 years).
- In-flood inspections. Performed by control authorities when managers report safety issues.
- Post-flood inspections. Performed by control authorities when managers report safety issues.
- Special inspections. Control authorities can perform special inspections, particularly when there are safety issues or planned modifications.

Figure F-6: Post flood inspection finding evidence of leakage in the masonry revetment, probably involving an important void behind the revetment, filled with water during the flood (source: Rémy Tourment)

Safety assessment and risk analysis have to be conducted at least every 10 years for Class A levee systems, every 15 years for Class B levee systems and every 20 years for Class C levee systems. They should (as indicated in the figure 5.1 of the ILH) be used as a decision making information tool.

Flood event management is not defined by regulation, but it has to be defined at the local management scale, and described in a written document. Each Mayor of commune must carry out a communal safeguard plan (Plan Communal de Sauvegarde, PCS). A PCS consists of formalising the organisation of crisis management for the various risks to which the municipality is subject, floods in particular. It must identify the risks and associated vulnerabilities for the municipality, define the PCS trigger conditions, and plan the organization of alert, information, protection and support of the populations, for each type of risk. Rescue of populations is carried out by fire brigades, and by accredited associations of civil security. Municipality reserves (Réserves Communales) can also provide volunteers to help for rescue missions or watercourses and levees watches.

6.7 Critical knowledge, data gaps and research needs

About levee and flood protection structures, the first knowledge gap consists in the need for identification of all existing structures and associated owners/managers. In fact, many existing flood defence structures are still unknown from State control authorities. The second gap consists in the need for data (i.e. structural data) to characterize these existing structures.

About general knowledge for levee management, hydraulic event probability estimation and inundation modelling activities are classic engineering and research topics with updated tools and methodologies, related mainly to hydrology and hydraulic disciplines. However, research is still needed and notably to better estimate marine hydraulic loads on coastal levee systems. More research is required in geomechanics, to better understand failure/breach mechanisms and sequences of mechanisms, and to better model complex failure scenarios, notably in contexts of transition between different kinds of structures. Real-time survey tools, monitoring techniques and repair techniques, for levee systems, have also to be improved.

Levee systems risk analysis is a relatively newly defined activity. Even if recent research projects have demonstrated significant advances in the development of methods to conduct these risk analysis, this activity still presents important challenges in terms of the design of credible and reliable methodologies, especially about 'levee system failure analysis', 'flood consequence analysis' and 'risk attribution' steps. These challenges and aspects requiring further development include those relating to the communication of the model results and the technical aspects of the methodologies; levee data sufficient to support the reliability analysis; and also to simplifications inherent within methods of flood inundation modelling that are applied in practice.

6.8 Summary of Key Facts

- About 9000 km of levees (roughly 90% inland and 10% coastal)
- Usually from locally available earth material, height usually up to 6 m.
- Annual flood damage in the order of 1 billion Euro/yr, roughly 25% insured
- 18 million people live in potential flood hazard areas, 2 million people and 20000 km² (roughly 3% of France) are protected by major flood protection systems.
- Some recent flood defence failures, but no failures until 1993
- Levees have no explicit role in Floods Directive implementation
- Similar legislation for levees, dams and other protection structures
- Common practices and obligations depend on levee type/class (depending on height and protected population)
- Many levees to be inspected for first time; for high-risk levees in-depth inspections/assessments every 1-10 yrs.
- Governance: various parties involved: from state to municipality to home/ land owner
- No prescriptive guidelines, but various informal guidance documents
- Annual investment typically 7.5 to 104 k€/km, annual maintenance typically 4.4 to 8.5 k€/km, annual management typically 2 to 3.8 k€/km.

6.9 References

- Policy for the management of flood risk: http://www.developpement-durable.gouv.fr/IMG/pdf/13195-2_deploiement-polit-gestion-risques-inondation.pdf
- National strategy for flood risk management: http://www.developpement-durable.gouv.fr/La-strategie-nationale-de-gestion,40051.html
- Preliminary flood risk evaluation (2011): http://catalogue.prim.net/190__evaluation-preliminaire-des-risques-d-inondation-nationale.pdf
- CFBR (and other) documents: http://www.barrages-cfbr.eu/Recommandations.html
- Référentiel technique digues : http://www.barrages-cfbr.eu/IMG/pdf/referentiel_technique_digues_maritimes_et_fluviales.pdf
- Guide enrochement pour les ouvrages hydrauliques : http://www.eau-mer-fleuves.cerema.fr/guide-enrochement-l-utilisation-des-enrochements-a407.html
- Coût des protections contre les inondations fluviales, ed, Connaissances. Cerema, Bron.: http://www.eau-mer-fleuves.cerema.fr/cout-des-protections-contre-les-inondations-a1313.htmlr.

7 Germany

7.1 Facts and figures on levees and flood defences

In Germany large areas of the coasts of the North Sea and the Baltic Sea as well as along many rivers are protected by levees or flood walls. In some cases these flood defences are completed by demountable elements mostly due to architectural or environmental reasons. All common types of flood defences are being used in Germany. Figure D-1 gives a schematic overview of the existing flood protection works.

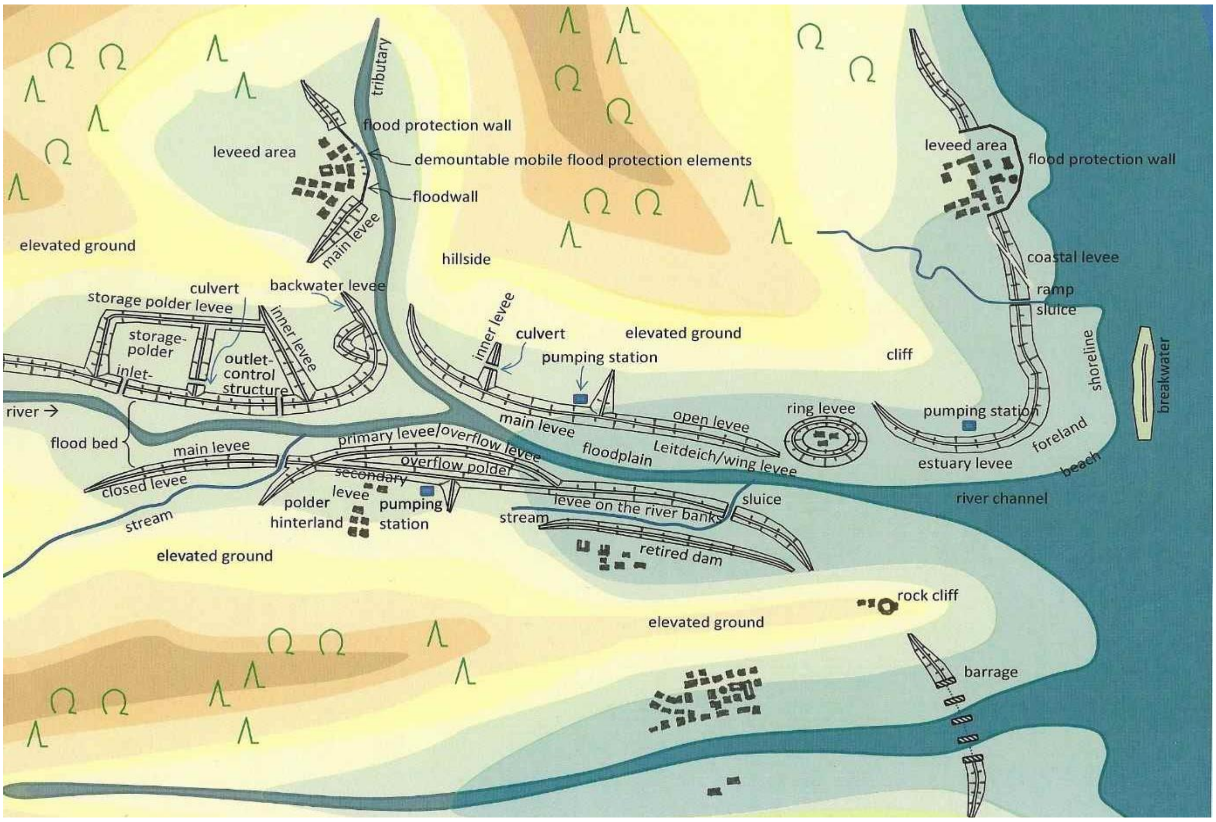

Figure D-1 Types of flood defences in Germany (Pohl 2013)

The distribution of the levees by flooding source may be estimated as follows in Table D-1.

Table D-1 Estimated percentage of flood defences (of each type) linked to physical environment / flood threat

physical environment / flood threat	Estimation for Germany	Estimation for Saxony	Example of a Water Association in North-Rhine Westphalia: Emschergenossenschaft/Lippeverband
Sea	20	-	-
Estuary	3	-	-
Lake	< 1	2	-
River	73	94	100
Torrent	3	4	

The supervision of flood protection in Germany lies in the hands of the authorities of the 16 federal states (Introduction Law to the German Civil Code (EGBGB) Art. 66). The organization of flood protection differs from one federal state to another and is regulated by the Water Laws of the different states. In some states, the state itself is responsible for flood protection works and their maintenance.

Elsewhere this work is done by communities, water associations, private persons or organizations and only the supervision is carried out by the authorities.
Hence no nationwide levee inventory exists and some of the following information in this chapter can only be given as examples for certain districts or catchment areas.

The dam authority of Saxony is responsible for about 690 km of levees (among them 370 km reinforced since the 2002 flood), about 100 km of flood walls and 10 large pumping stations. There are other levees and flood defences owned by smaller communities and associations in the Free State of Saxony. There are 1312 km of levees in Saxony-Anhalt and 193 km in the area of the Emschegenossenschaft / Lippeverband in Northrhine-Westphalia. An exact number for the total length of all levees in Germany cannot be given, because it is difficult to define a lower limit of levees.
The height of the levees varies from 50 cm to about 16 m where the levee height is defined as the vertical distance between the landside crest level and the ground level at the landside toe.
It is noteworthy that there are leveed rivers, especially in North-Rhine Westphalia, where the thalweg is higher than the surrounding ground elevation because of large area subsidence due to underground coal mining.

Table D-2 Range of Levee Heights

Levee height [m]	Estimation for Germany	Estimation for Saxony	Example of a Water Association in North-Rhine Westphalia: Emschergenossenschaft/Lippeverband
Minimum	0,50	0,50	1
Mean	4	2 … 3	5
Maximum	16	6	16

Figure D-2 Levees at the floodplains of the Elbe river (federal waterway) and on both sides of the flood bypass channel downstream the city of Dresden at Kaditz Village in the centre of the picture (photograph: R. Pohl)

The History of levees in Germany goes back about 2000 years: The first Levees from the Roman period with a height up to 1,20 meters were found in Friesland on the North Sea Coast. They were erected to protect agricultural areas against inundation and resulting saltination of the topsoil. The first coastal levees were ring-levees which were connected later to form a closed dike-line at the end of the 13th century. Also the estuaries of the rivers became leveed.

The levees broke from time to time and were rebuilt and heightened step by step, mostly after a breach due to overtopping during a severe flood. Major floods on the German North Sea coast were reported e.g. 1634 (Burchardiflut), 1717, 1825, 1962 (Hamburg-Sturmflut).
Until the 17th century levee maintenance was the task of the coastal land owners. Often the duty of levee maintenance overwhelmed the local people so that they gave up, stuck the spade into the levee crest and left. Those who took the spade got the land and accepted the obligation of levee maintenance. All legal relationships related to levees were regulated by laws like the Bremen Levee Law from 1473.
Later Levee Associations were founded, which still organize the flood protection in some federal states of Germany .

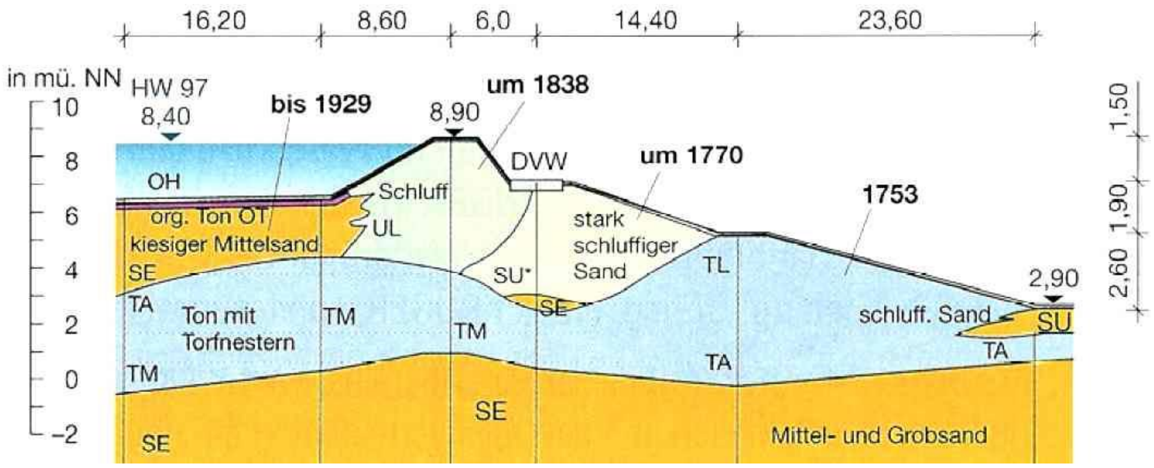

Figure D-3 Historical development of a levee. Cross section of the Oder-Levee at km 69.45 south of Hohenwutzen (from Krüger et al. 1999)

Some of the disastrous levee failures happened during a storm flood on 16/17 February 1962 in Hamburg and the North Sea Coast, where the levees broke at about 30 sites and 340 people lost their lifes. After this catastrophe the levee lines were straightened, the levees were heightened (up to +8 m asl.) and new levees were built. In the Elbe estuary downstream of the Geesthacht weir, today levees on the left bank of the Rvier Elbe with a length of 135.6 km protect a hinterland of 1309 km², on the right bank 99.5 km of levees protect 856 km² and in the city of Hamburg 250 km² is protected by 99.5 km long levees. The total population in this leveed area is 475000 inhabitants (Simon et al. 2005).
In the middle reach of the Elbe the first levees were built in 1160 from Elbe 412 to 450 km. Today the hinterland (3285 km²) of the Elbe river with 365000 people is flood protected from 97.7 km (downstream Hirschstein Castle) to 585.9 km (Geesthacht Weir) with about 730 km levees (Simon et. al 2005). The upper Elbe has about 20 km of levees in Germany in the area of Dresden with about 50 km in the Czech Republic.

Table D-3 percentage of flood damages in the case of a levee failure

Levee height [m]	Estimation for Germany	Saxony: no information available	Example of a Water Association in North-Rhine Westphalia: Emschergenossenschaft/Lippeverband
Almost no hazard	5		16
Material hazard only	45		0
Some life hazard	45		24
Large scale life hazard/economic hazard (say > 100 people/over 100 million €)	5		60

In the case of an unforeseen levee failure large damages could arise. Table D-3 gives an indication of which kind of hazard could be expected.

The typical construction and/or rehabilitation costs for 1 km of levee can vary considerably depending on the boundary conditions (height, underground, availability of construction material in the vicinity, level of protection, real estate, compensation, …). Estimated costs range from 100000 €/km to 2.5 million €/km. In Saxony and probably in the most of the other federal states no official statistics concerning the levee costs are available.

7.2 Protected value, safety standards and flood risk in Germany

According to the German guidelines and standards different levels of protection are recommended depending on the utilization of the hinterland. The values in Table D-4 are normally applied to fluvial levees all over Germany.

Table D-4 Object categories and possible assignment of damage potentials as well as of reference values for the flood recurrence interval (DWA-Guideline 507-1 for fluvial levees and DIN 19712:2013, Table 2)

Object category	Damage potential	Standard reference values derived for the average statistical recurrence interval T_n [in years]. The annual failure probability is $P = 1/T_n$
Special items with extraordinary consequences in the case of flooding	high	To be determined on a case-by-case-basis (in practice recurrence intervals up to 500 years are justifiable and have already been applied.
Urban areas	high	≈ 100
Industrial Plants and Facilities	high	≈ 100
Supraregional Infrastructure Facilities	high	≈ 50 … 100
Single buildings, settlements not permanently inhabited	medium	≈ 25
Regional Infrastructure Facilities	medium	≈ 25
Agricultural Areas	low … medium	up to 5
Natural Landscapes	low	-

Besides these criteria the cost-benefit ratio, the licensability and environmental impact also affect levels of protection. As there is no statistical information available it is estimated that about 12 million people (15%) in Germany might be protected by levees. In the example-area of the above mentioned Water association about 4.1 million people and more than 2 Billion € asset values are protected by levees against floods.

Depending on the structure height above the landside toe and the hazard/damage potential the Flood protection works are classified (Table D-5):

Table D-5 Classification of flood protection works in Germany

structure height	hazard/damage potential		
m	high	Medium	Low
$H \geq 3$	class I	class II	class II
$3 > H \geq 1.5$	class I	class II	class III
$1.5 > H$	class I	class III	class III

7.3 Recent major floods and failures of levees

During recent decades many flood events have been observed in Germany. The major floods were in 1962 from the North Sea (s. above), 1997 and 2010 in the Oder-watershed, 2002 and 2013 in the catchment areas of the Elbe and Danube rivers with property losses up to 6-7 Billion € (2002). While in the recent events none or only a few people have lost their life more than 300 people died in Hamburg during the 1962 storm tide. After these and many other events the flood protection works were rebuilt, heightened and updated. In Dresden, where many levees and floodgates were rebuilt or built after 2002, it was noticeable how well all newly completed defences worked during the 2013 summer flood. During the floods a permanent inspection of the protection works takes place (e. g. in Saxony according to § 85 section Sächs WG). In some cases the evacuation of the people in the lower areas of the hinterland was organized during the above events.

About once in ten years a flood event with fluvial levee failures and large property losses has been recorded in Germany over recent decades.

Figure D-4 Levee Failure at the Oder 1997 near the village Wiesenau. Foreground:large scourholes in the levee axis. Background: remaining levee cross section. Trees at the landside toe hindered the levee slope inspection. On the right side: the Oder river. (photograph: R. Pohl)

Articles from several viewpoints about some of these incidents are in technical journals in Germany like "Wasserwirtschaft" (Pohl, R.; Franke, D.; Engel, J.; Niesche, H.; Krüger, 1999; Bornschein, A., Pohl, R., 2005; Pohl, R., Horlacher, H.-B., Müller, U, 2006 pp 597-615; Brauneck, J., Jüpner, R., Pohl, R., Friedrich, F., 2016).

Further reports from Saxony with the event analysis can be downloaded for free at:

http://www.smul.sachsen.de/lfulg/35756.htm (2010 und 2011 floods)

https://publikationen.sachsen.de/bdb/artikel/15180 (2013 floods)

7.4 Legislation and governance

7.4.1 Implementation of EU Regulations

River basin management and flood protection are organized according to the European Water Framework Directive (2000) as well as to the Floods Directive (2007) are the basis for river training measures and the organization of flood protection.

7.4.2 National Legislation

The basic principles for water management and flood protection are given in the federal Water Resources Act and in the water legislation of the 16 federal states (Bundesländer). They are responsible for flood protection (Introduction Law to the German Civil Code (EGBGB) Art. 66). The organization of flood protection differs from one federal state to another and is regulated within the Water Laws of the different states (e.g. in Saxony: § 85 Abs. 2 Sächs WG).
According to the responsibility for the structures along navigable federal waterways, there is a distinction between lower or navigable water levels (discharges) and the flood discharges beyond. For the waterways and its dams up to the navigable water level, the responsibility lies in the hands of the national government (Ministry of Transport). For flood protection at higher water levels, the federal states are responsible.

For large dams (i. e. barrages, German: Talsperre) which fulfill the ICOLD criteria ($H \geq 15$ m; $S \geq 1\,000\,000$ m³) a nationwide inventory exists. They are also listed in the ICOLD dam inventory. The most medium-sized dams (15 m > H ≥ 6 m; 1 000 000 m³ > S ≥ 100 000 m³) are registered in databases of the federal states, their authorities or the owner companies. The small dams might be registered by the communities on whose ground they are situated.
For levees there is no nationwide inventory available. Those who are in charge of the levees and other flood defences (s. above) normally have inventories of their own protection works. It is not in all cases clear from which lower limit a levee has to be regarded as a levee for flood protection in the sense of the levee standard and guidelines.

7.4.3 Governance

As mentioned before, the supervision of flood protection in Germany lies in the hands of the authorities of the 16 federal states (Introduction Law to the German Civil Code (EGBGB) Art. 66); the main features of flood protection governance are given in Table D-6:

Table D-6 Responsibility for flood protection in the federal states

Federal State (Bundesland)	Responsible for flood protection and maintenance of flood defences
Berlin (city state)	Senate
Hamburg (city state)	Senate
Bremen (city state)	Senate
Schleswig-Holstein	Levee associations /Water boards for fluvial and coastal levees
Mecklenburg- West Pomerania	The federal state is responsible for constuction and maintenance of state flood protection works (appendix 2 des LWaG). All other flood protection works: Water Boards and Land Associations (s.a. § 73 LWaG).
Lower Saxony	Levee associations /Water boards for fluvial and coastal levees
Rhineland-Palatinate	
North-Rhine Westphalia	Levee associations /Water boards
Federal State (Bundesland)	Responsible for flood protection and maintenance of flood defences
Saxony	Rivers of 1st order, federal waterways, border rivers: state owned enterprise “State Reservoir Administration of Saxony - LTV” (§ 80 Sächs WG), smaller rivers of 2nd order communities (or private persons/organizations) Flood defence: Communities supportet by LTV (§ 84 section 1 SächsWG and § 85 SächsWG) Flood early warning message service: LfULG (HWNAVO)
Thuringia	Levees at rivers of 1st order Free State of Thuringia, smaller rivers of 2nd order: communities

Brandenburg	Rivers of 1st order (big or importend): State Environment Agency, 2nd order (small rivers): Water Boards and Land Associations Flood protection and levees: federal state; flood control and emergency management: County Administration (Civil Protection Office)
Baden-Wuerttemberg	Rivers of 1st order: State Ministry for Environmental Affairs, smaller rivers communities or private persons/organizations
Bavaria	Rivers of 1st, 2nd order: State Ministry for Environmental Affairs, 3rd order (small rivers) communities or private persons/organizations
Saarland	
Hessen	State and private Flood Protection, depending on property
Saxony Anhalt	Rivers of 1st order: State authority for flood protection and water management Saxony-Anhalt (LHW) Rivers of 2nd order: Water Maintenance Associations, communities or private persons/companies/ organizations

7.5 Guidelines and good practice in Germany

Figure D-5 Levee at the Elbe in Dresden. View upstream from Washington st. bridge (photograph: R. Pohl)

In Germany the general accepted codes of good practice for hydraulic structures are given by the national standards (DIN Deutsches Institut für Normung, formerly Deutsche Industrie-Norm) and the technical guidelines of the German Association for Water, Wastewater and Waste (DWA = Deutsche Vereinigung für Wasser, Abwasser und Abfall). All these regulations are only recommendations but they can get legal character if they are introduced officially by the state officials.

The related technical rules in Germany are mainly:

- DIN[2] Standard 19712 Flood protection works at flowing waters (1997, new issue 2013)
- DWA[3] Guideline 507-1 in German and English, Levees along watercourses (2011)

[2] Deutsches Institut für Normung e. V. - German Institute for Standardisation, Berlin

[3] Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. - German Association for Water, Wastewater and Waste, Hennef

- DWA Guideline 507-2 Levees along watercourses: Landscape ecology (pending, 2018/19 expected)
- DWA Guideline 507-3 Sealing systems in levees (2005, new guideline planned)
- Recommendations for Coastal Levees (EAU)
- DWA Guideline 512-1 Sealing systems in hydraulic engineering. Part 1: Earthen structures.
- BWK[4] Guideline 6 Demountable flood protection systems (2006)
- MSD[5] Guideline Stability of dams (1998, 2011)

In addition, there are the guidelines of the authorities in the federal states available, especially concerning flood defence activities during extreme events beyond the design discharges. Further related standards and guidelines can be found in the list of references.

As the ICOLD Bulletins are mainly made for dams (barrages) they have not been used for levee design in Germany in the past. Some of them might be applicable (like Internal erosion) or can be used with some adaption. The International Levee Handbook is being used occasionally to get supplementary information for issues beyond the scope of the national or federal standards and guidelines.

Figure D-6 Some standards and guidelines for fluvial levees (left) and coastal levees (right)

7.6 Common practices during Levee Life Cycle

Design practice is usually based on the above mentioned standard and guidelines as well as on local experience.

Inspection of levees is normally made at least once a year (s. a. DIN 19712:2013-01, section 15.4.2) in spring or early summer after the snow melt in the mountains. Additional inspections are made after extreme flood events to check if the defences have been damaged. Also, the responsible authority inspects the watercourse and protection works (e. g. in Saxony according to § 93 Abs. 1 SächsWG).
A more detailed levee safety assessment is programmed to be made every 5 to 10 years. The results have to be compiled within a status report.
Flood event management is carried out in most cases and in most communities by the local fire brigades under the supervision of the authorities of the federal states. During very severe floods the Technical Aid Organization, volunteers and the Army help to defend the flood protection works.
After each flood an event analysis from the hydrological and technical viewpoint is made. In Saxony 1600 proposals for measures were derived from these analyses which are being realized step by step.
Since 2006 in Saxony 362 levee status reports for 380 km of protection works have been made.

[4] Bund der Ingenieure für Wasserwirtschaft, Abfallwirtschaft und Kulturbau e. V. - Union of Engineers for Water, Waste Management and Soil Improvement, Aachen

[5] Bundesanstalt für Wasserbau - Federal Waterways Engineering and Research Institute, Karlsruhe

7.7 Critical knowledge and data gaps; critical research needs

In most cases a conventional design procedure is used. This is risk based insofar as the Table D-5 is taken into account. Risk based procedures on the basis of probabilistic approaches are more rarely used.

For instance in Saxony-Anhalt 57 per cent of the 1312 km levees could be refurbished to meet the technical standards within the last few years . Even in 2015 in this state 110 million Euros were spent implementing flood protection and levee repairs in Saxony-Anhalt. Conversely this means that 43 % of the levees will have to be upgraded in the near future. It might be assumed that the situation is more or less similar in the other federal states.

Future issues could be the development of prediction methods for the levee safety based on the levee condition (status) as well as a real risk mapping based on the integral of probability and consequences according to the risk definition R = P x C. At present the "risk maps" (in fulfilment of the EU directives) are hazard maps and inundation maps respectively, with additional information about population at risk, critical infrastructure, hospitals, police stations, chemical industry etc. Another gap of knowledge results from the 100 m distance for ground and levee exploration. Historical grown levees are often highly heterogeneous and can change their properties within these 100 m so that they are actually 3-dimensional structures.

Summary of key facts

Table D-2 Summary of levee facts in Germany (grey numbers are estimations)

Item	Germany (total)	Saxony	Saxony-Anhalt	NRW: only Emscher-genossenschaft/ Lippeverband
Total levee length (km)		**650**	**1312**	**193**
- Therefrom hard protection		**100**		**1**
- Therefrom demountable		2		
- Structures in the levee				**200**
Percentage of Coastal levees	20	**0**	**0**	**0**
Percentage of Estuary levees	3	**0**	**0**	**0**
Percentage of Lakeside levees	< 1			**0**
Percentage of Fluvial levees	73			**100**
Percentage of Torrent levees	3			**0**
Maximum levee height	16	5	4	**16**
Medium levee height	4	2	2	**5**
Minimum levee height	0.50	0.50	0.50	**1**
In the case of levee failure - no hazard (percentage %)	5			**16**
- material hazard only (%)	45			**0**
- some life hazard (%)	45			**24**
- large scale life hazard (%) (> 100) / economic hazard	5			**60**
Typical construction/ rehabilitation costs €/km	10000… 2000000			**10000… 100000**
Typical maintenance/ management costs €/km ·a				**5000**
Levee-protected population (mio)	15			**4.1**
Levee-protected material assets (m€)	150000			**2000**
Percentage of levees meets the generally accepted codes of good practice			**57**	**98**
Levee failure(s) within the last two decades	**yes**	**yes**	**yes**	**no**
Major Floods with levee failures within the last two decades	**1997 2002 2010 2013**	**2002 2010 2013**	**2002 2013**	

- In Germany there are about 10 000 km of levees and thousands of adjacent structures.
- It is estimated that about 20% of the levees are coastal and 80% fluvial.
- The levees protect over 12 million people and at least 2 billion Euro in asset value.
- The safety standards are set by the actual standard DIN 19712 and the DWA Guideline 507-1 as well as the EAU-Recommendations for the coast. The level of protection for densely inhabited areas is normally 1/100. More values are given in Table D-5.
- Recent levee failures occurred e.g. in 1997 at the Odra river and 2002 and 2013 at the Elbe and Danube.
- The standard DIN 19712 and the DWA Guideline 507-1, as well as the EAU-Recommendations, are the main guideline documents for levee planning, design, and assessment. ICOLD Bulletins and the International Levee Handbook may be consulted but play no key role.
- Governance reflects the fact that Germany consists of 16 Länder in which governance may differ.
- Key knowledge gaps: flood risk prediction and mapping using the actual condition of levees, and knowing the levee and its underground in greater detail.

Figure D-7 Levees at the Emscher river in Oberhausen
(Photograph: Emschergenossenschaft-Lippeverband in GRÜN, JOHANN, PFISTER 2014)

7.8 References

German Standards and related Guidelines

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8 Italy

8.1 Facts and figures on levees and flood defences

Italy has a national register for large dams, but not for flood defenses.

The Research Institute for Geo-Hydrological Protection has recently developed the ItaliaN LEvee Database (INLED). INLED has the main focus of collecting comprehensive information about levees and historical breach failures to be exploited for the assessment of levee vulnerability. Currently, INLED mostly contains data of the Tiber basin, Central Italy.

Italy has been recently subdivided into 8 hydrographic districts. This document mainly focuses on the Eastern Alps district and Po district (district 1 and 6 in Figure IT-1).

Figure IT-1: Hydrographic districts responsible for the application of the Flood Directive.

Another important player are the Land Reclamation Consortia. They manage about 50% of the national territory, including the whole plain, large parts of the hills and a small part of the mountain areas. They take care of drainage and irrigation systems and they monitor the activity of private players. As a matter of fact, in Italy over 1 million hectares require mechanical drainage. The costs of the normal maintenance are afforded by the members of the consortia, while public money is needed for the exceptional maintenance necessary to modernize the systems and adapt them to the transformation that the environment is experiencing.

Levees extent and geographical context

The Eastern Alps district covers 12.5% of the national surface and includes 6 main rivers that flow into the upper Adriatic sea. It counts 2700 km of levees of strategic importance (category 2, see Sect. 4.3 about categories) and nearly 1200 km of levees of category 3 (Table IT-1). The Po River is the longest and most important Italian watercourse, with over a hundred tributaries. Its district counts nearly 2300 km of dikes of category 2.

Land Reclamation Consortia are responsible for 9233 km of minor river and sea levees and 754 pumping stations all over the national territory. This data was provided by ANBI (National Association Land Reclamation Consortia) and refers to 2005, but a new census is ongoing. Updated data was provided by the Land Reclamation Consortia of the Venetian plain (Veneto Region and Friuli Venezia Giulia Region). They state that they manage 2450 km of levees with average height of 2 to 3 m (Table IT-2). A few private consortia, with their own pumping stations, also exist.

The largest part of the flood defenses belongs to natural river environments and artificial channels for drainage and irrigation. Defenses from the sea do represent a significant percentage (likely around 10%) while lake defenses do exist but represent a small percentage. Torrents are partly protected by levees of small size. Another category is represented by the levees delimiting detention basins.

The most typical defense are embankments, but there are also floodwalls, sometimes on top of embankments, and gates.

A peculiarity is represented by the defenses, called murazzi, built in the 18th century on the islands delimiting the Venice lagoon to protect the city of Venice from flooding (Figure IT-2). They have been recently integrated by groynes to promote sand deposition. The city of Venice will be further protected by the MOSE (MOdulo Sperimentale Elettromeccanico, Experimental Electromechanical Module), consisting of rows of submerged movable gates installed at the three inlets to temporarily isolate the lagoon from the sea during high tides (Figure IT-2). The structure is expected to be in operation by the end of 2018. Its construction required a great deal of geotechnical investigations and experimental studies to evaluate the compressibility and strength of the foundation soils.

In the upper Adriatic sea the problem of saltwater intrusion is quite relevant. In order to stop it, flap gates have been installed at the estuary of the Adige River and at two branches of the Po delta. Sluice gates are present at the Caorle lagoon and the construction of a new barrier at the estuary of the Brenta river is under evaluation. Like embankments, these gates are prone to piping. The lower part of the gate can be prolonged into the subsoil to work as a cut-off for piping prevention.

Table IT-1: Levees administrated by the Basin Authorities in the Eastern Alps district.

River basin	Levees of category 2 (*)(**) [km]	Levees of category 3 (*) [km]
BRENTA-BACCHIGLIONE	974	641
PIAVE	102	12
LIVENZA	396	89
TAGLIAMENTO	152	100
ISONZO	114	189
Total Upper Adriatic Basin	**1738**	**1031**
ADIGE	959	155
Total	**2696**	**1187**

(*) Source: Magistrato alle Acque Venezia (**) Average height: 4-5 m

Table IT-2: Levees administrated by Land Reclamation Consortia in the Eastern Alps district.

Consortium	Levees administrated* [km]
Alta Pianura Veneta	300
Brenta	150
Adige Euganeo	315
Bacchiglione	500
Acque Risorgive	261
Veneto Orientale	429
Piave	110
Adige Po	150
Ledra Tagliamento	10
Bassa Friulana	225
Cellina Meduna	not available
Total	**2450**

(*) Average height: 2-3 m

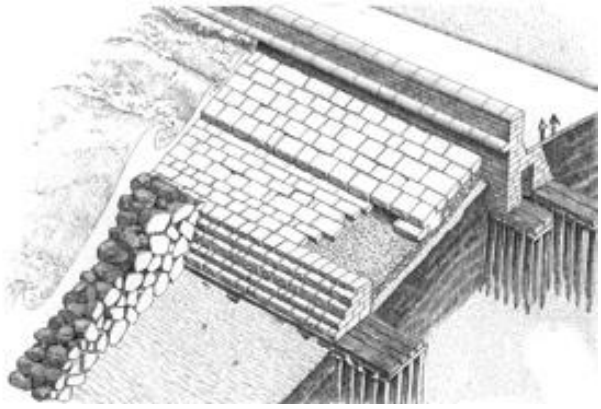

Figure IT-2: Picture of an old murazzo, the hystorical defences of the Venice lagoon from storm surges.

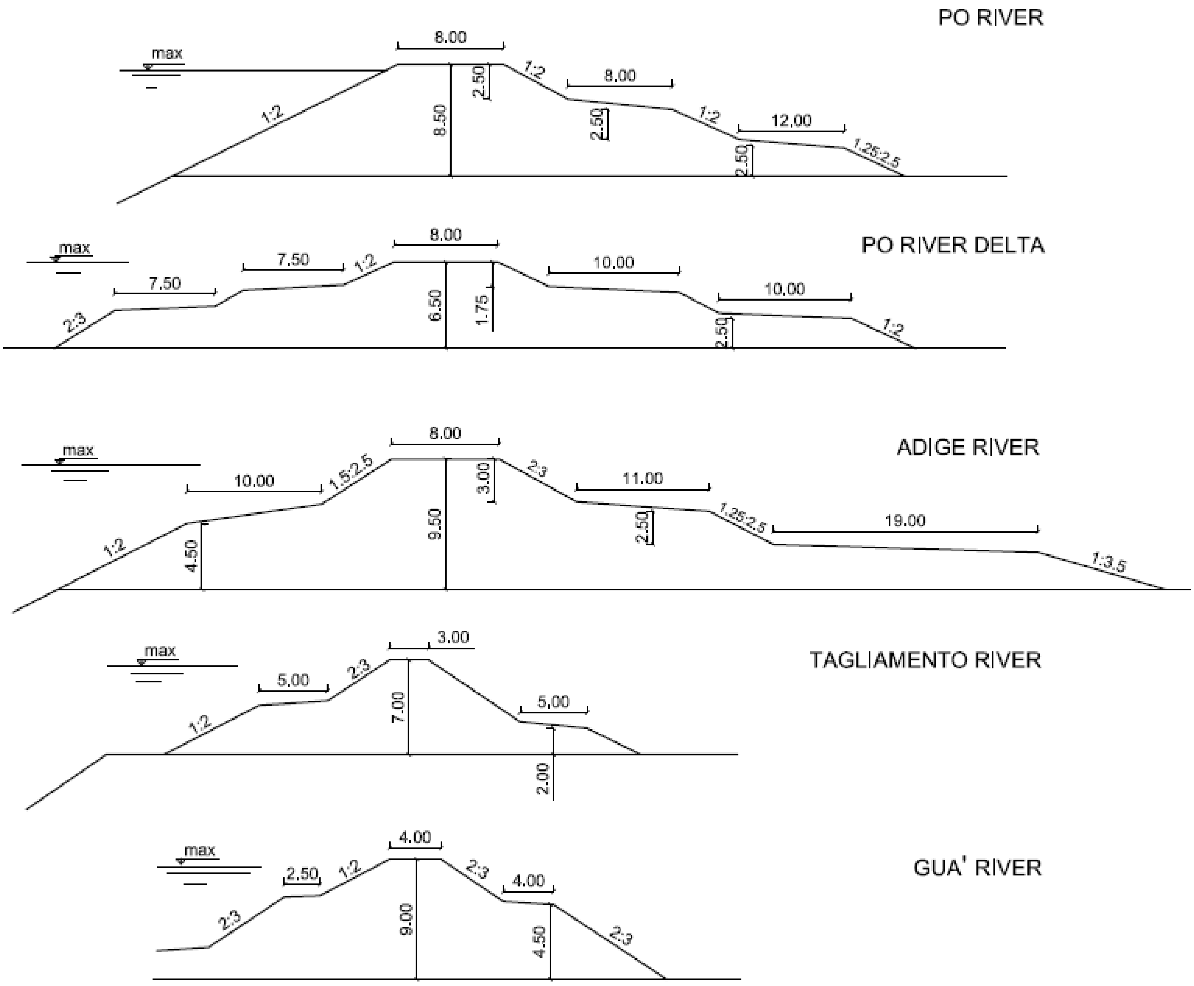

Figure IT-3: Typical embankment cross-sections of rivers in Northern Italy.

Typical size and materials

In the Eastern Alps district, river embankments have an average height of 4 m, a maximum height of 11.0 m above the ground level and a minimum height of 0.5 m.

The Po and Adige rivers are the longest Italian rivers: 652 and 410 km respectively, almost completely in the national territory. The Po river has a maximum recorded flow rate of 10.300 m^3/s (Pontalagoscuro, 1951 flood).

In the lower course of the Po and Adige river, levees have wide cross-sections (over 60 m) to prevent instability and piping. The upper course of these rivers and the other rivers of the districts have smaller levees. A sample is given in Figure IT-3.

Flood embankments have been built and repeatedly reinforced across the past few centuries using the materials at hand. For this reason, their composition is strongly dependent on their environment. Moreover, although the scheme adopted is often that of a homogeneous embankment, some heterogeneities are often present, both in terms of soil composition and in terms of degree of compaction. Discontinuities between successive reinforcements are also possible.

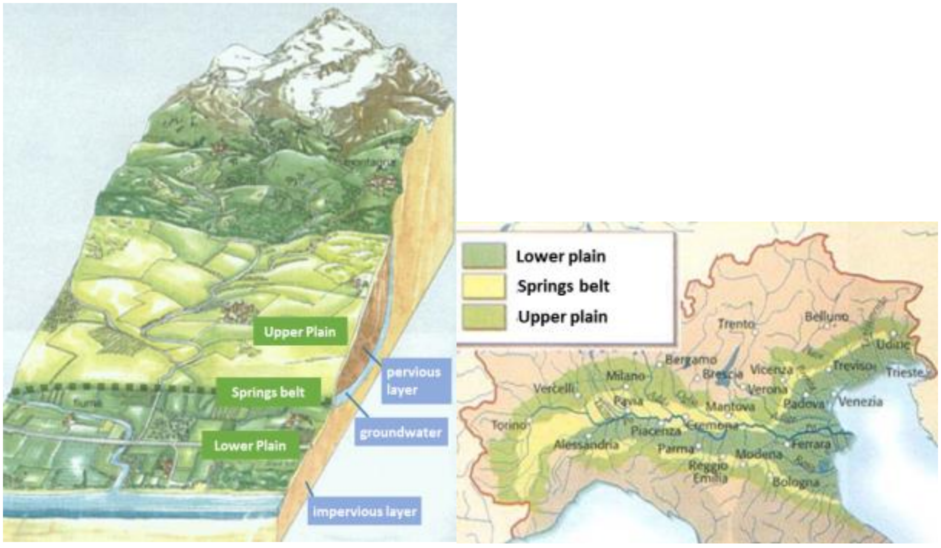

Figure IT-4: Upper and lower plain.

In a flood plain, as the Po plain and the Venetian-Friulian plain, two distinct areas can be identified: the upper and the lower plain (Figure IT-4). The upper plain extends next to the hills and it is made of heavy debris as cobbles and gravel. Here rain water infiltrates deeply in the subsoil up to an impervious layer that partly blocks its way, giving rise to a large water deposit: the groundwater. Groundwater flows very slowly toward the sea. The impervious layer, made by fine and light debris, as sand and clay, is typical of the low plain. At the border between the upper and lower plain the spring belt arises. It is the strip of land where part of the underground water emerges to continue its cycle on the surface.

In broad terms, it can be said that in the upper Po and Venetian plain, levees generally have a body of sand and gravel, covered by a clayey/silty soil; if needed, on the riverside they are protected against erosion by a quarrystone armor layer or by concrete slabs (again depending on the material at their disposal) and by a toe stone protection. In the lower plain levees are mostly made of fine material, from silty sand to silty clay. In some Alpine valleys dikes are made of tout-venant .

Diaphragm walls are very often installed in existing levees to avoid through-seepage and underseepage. They are made of concrete, jet-grouting or bentonite-cement slurry, less frequently of sheet piles. For instance, the levees of the lower course of the Adige river (150 km) are reinforced by more than 50 km of diaphragm walls and much more would be needed (Regione del Veneto, 2003). Often these barriers do not reach a deep layer of low permeability and/or their joints are not perfectly executed, so that they are not very effective in reducing the pore pressures at the landside.

The current profile of the embankments of the Po River is defined by the guidelines released in 1873, 1952, 1998, 2007 and 2010. The 1873 guidelines recommended:

- the top safety margin: 80 cm in the upper course, 100 cm in the medium and lower course, 60 cm in the delta reaches;
- the width of the crest;
- the slopes: 1:1.5 above water level and 1:2 below water level, on the riverside, 1:2 on the landside;
- the shape of the berms.

The 1952 guidelines, released after the 1951 flood, recommended that the section should contain the "theoretical piezometric line" with slope 1:6 from the maximum water level; the reinforcements had to be preferably executed on the landside.

The 1998 guidelines, released after the hydraulic studies following the 1994 flood, recommend to execute the reinforcements on the riverside because:

- the economical value of the ground is lower on the riverside;
- a smaller amount of construction material is required (Figure IT-5);
- demolition of paved paths on the crest is avoided;
- using materials of low permeability the hydraulic resistance of the levee is improved;
- the riverside slope can be reduced to 1:2 to avoid sloughing in the decreasing phase of the flood;
- the activities such as benching, executed to ensure a good connection between the old and new levee portion, shaping and sowing on the new slope involve a smaller surface.

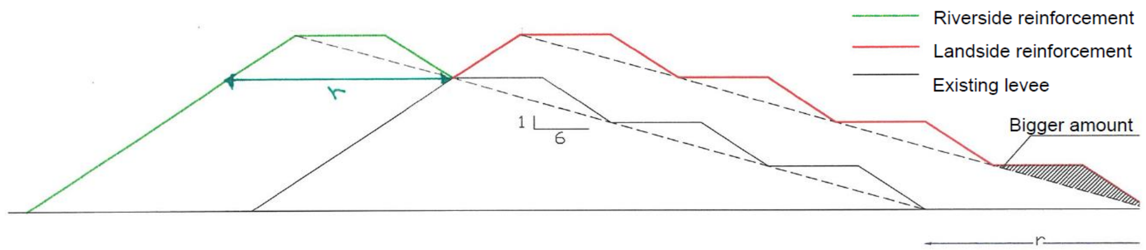

Figure IT-5: Comparison between riverside and landside reinforcement (Magistrato per il Po, 1998).

In 2007 a supplement to the guidelines was released after a large experimental study. It takes into account transient load conditions and the effect of partial saturation on the strength of the construction materials. It is recommended:

- to execute the riverside reinforcements with materials of low permeability A-7 to A-6, with sand content lower than 15%;
- to build a cut-off 1 to 2 m deep at the riverside toe to improve the connection of the new portion of embankment to the ground; build intermediate berms when the levee is taller than 5 m (Figure IT-6);
- to execute the landside reinforcements with materials more permeable than the embankment soil, type A-6 to A-4, with sand content higher than 50%;
- to use Proctor standard density as reference for in situ compaction;
- to build continuous cut-offs when the foundation material is permeable, with sufficient length to intersect completely the permeable layer;
- to ensure that the landside slope covers, by at least 1 m, the theoretical piezometric line with slope 1:5 to 1:6 (or 1:4.5 to 1:5.5 when the soil characteristics are well known and there is no piping hazard).

Based on another experimental study, in 2010 new indications were given for the reinforcement of the levees of the upper course of the Po River (Figure IT-7).

The profiles of the cross-sections of the levees of the medium and lower course of the Po River are collected in an atlas available online (Autorità di Bacino del fiume Po, 2004)

In some areas the main dikes are set back from the main river course and the areas between the river and the dike are often farmed. Trees for wood production, crops and, more rarely, fruit trees are grown. Along the Po River the main dikes can be as far as 5 km from the river.

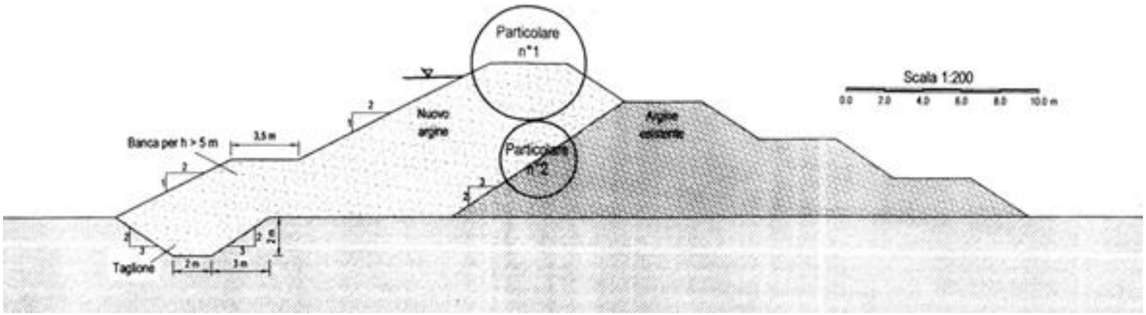

Figure IT-6: Riverside reinforcement according to guidelines for the reinforcement of the Po levees, 2007 supplement.

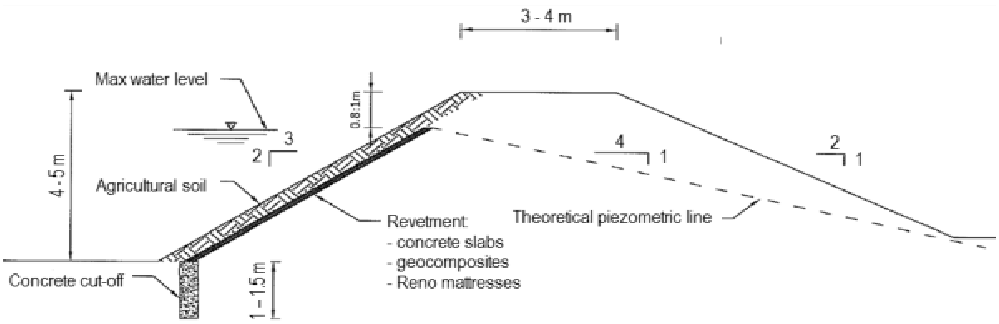

Figure IT-7: Example of reinforcement of a river embankment in the upper course of the Po river, 2010 indications.

Spending on levee management and levee reinforcement

The Italian government has destined 1.3 billion euro to be spent between 2015 and 2020 for the "metropolitan plan against flooding". 600 million euro have already been allocated for the protection of the urban areas at higher risk. A large part of the funds have been used to create new detention basins or enlarge existing ones and to improve existing levees.
The government has also established a 100 million euro fund (L. n. 221/2015) to be used between 2016 and 2018 for the design of interventions aimed at reducing the hydrogeological risk (also including landslide risk). The objective of the fund is to facilitate the design activities and to facilitate the beginning of the construction works. Priority is given to the design of interventions aimed at reducing the flood risk in metropolitan and urban areas where a large part of the population is exposed.

The Land Reclamation Consortium of the Verona province (administrated territory of 1600 km2) spends up to 300 000 euro every year for prevention and remediation of the damage induced by muskrats on levees.

8.2 Protected value, safety standards and flood risk in Italy

Flood risk

Some information about the residual flood risk in Italy (risk related to flooding despite the presence of levees) is contained in a report by ISPRA, the Italian National Institute for Environmental Protection and Research. ISPRA (2015) collected the data relative to the flood risk maps produced in 2013 by the hydrographic districts to comply with the Flood Directive. It must be pointed out that the procedures adopted by the districts to produce the maps were quite heterogeneous. Most importantly, not all the districts took into account the effect of possible levee breaching. Table IT- 3 reports the number of inhabitants and productive units prone to flood hazard. Italy also has a large artistic and architectural heritage. It has been calculated that for the medium probability scenario 29 005 items are endangered. Among the cities at risk there are Venice, Florence and Pisa. Rome also joins the list when the low probability scenario is considered. Only hazard and exposition are quantified by the maps; the quantification of vulnerability (percentage of the total value of an asset which is lost as a consequence of flooding) was postponed to the next assessment cycle. The risk was calculated as a product of hazard and exposition and classified into 4 categories from low to very high. No monetary information can be directly deduced from the maps so far.

Safety standards

Italy does not prescribe any safety standard for what concerns the hydraulic actions on its flood defenses. Most defenses have been raised across the years to retain the maximum water level ever recorded with a safety margin of 1 m.

For what concerns the seismic action, the reference period is chosen in accordance with the national code for the design of civil constructions (D.M. 14 gennaio 2008: Norme tecniche per le costruzioni). It depends on the service life and on the strategic importance of the structure.

In 1989 (L. n.183/89) six national river Basin Authorities and numerous river basins at the local level were instituted with the main task of elaborating basin management plans. After the catastrophic event of the Sarno landslide in 1998, they were asked to develop a Masterplan for the Hydrogeological Framework (Piano stralcio per l'Assetto Idrogeologico - PAI), according to the indications given in DPCM n.29/1998. These plans must map the hydrogeological risk and contain safeguard measures for the areas at risk. Flood hazard and flood risk maps are part of the plans. The hazard maps must identify at least three areas:

- high probability of flooding (20≤ T ≤50 years),
- medium probability of flooding (100≤ T ≤200 years),
- low probability of flooding (300≤ T ≤500 years).

The choice of the exact values for the return period is left to the Basin Authorities. Based on hazard and exposition, four classes of risk (R1 to R4) are defined.
The maps represent to date a compulsory tool for urban planning and the main tool for the planning and preliminary design of risk mitigation structures. Therefore, when designing or improving a levee, the medium probability flood adopted by the PAI in that river basin is often considered. However this is not a compulsory rule.

Table IT-3: Surface, inhabitants and productive units prone to flood hazard in Italy.

Scenario	Inundated area		Inhabitants	Productive units
	km^2	% national area		
High probability (20≤ T ≤ 50 years)	12 218	4.0 %	1 915 136	186 266
Medium probability (100 ≤ T ≤ 200 years)	24 414	8.1 %	5 922 922	576 535
Low probability (200 < T ≤ 500)	32 150	10.6 %	9 039 990	869 364

8.3 Recent major floods and (near-)failures of levees

Recent flood events caused several structural failures. The failures did not occur along the Po and Adige river that have wide cross-sections, reinforced across the years after severe floods. They occurred along other rivers that have much narrower and weaker cross-sections. Observed failure mechanisms are: riverside instability due to rapid drawdown, backward erosion piping, soft-hard structure transitions and instability/internal erosion promoted by animal burrows. In the following a detailed description of some failures is given.

"All Saints flood", Veneto, November 2010
Between 1 and 2 November 2010, 9 levee breaches and other overtopping events caused the overflow from the rivers Timonchio, Bacchiglione, Retrone, Alpone, Tramigna and Frassine. 140 km2 of territory were inundated, some areas for more than a week. The impact on the population and productive activities was heavy: three casualties, many injured, thousands of people evacuated and 151 thousand head of cattle dead. The flood caused the dispersion of pollutants from wastewater treatment plants, hydrocarbon tanks etc. On 5 November the national state of emergency was declared. The damage was estimated as 426 million euro. The unit cost of the flood, 3 million euro per km2, has been compared to the discounted cost of the 1966 flood, which resulted to be around 2 million euro per km2. The effect of the increasing urbanization and economic growth on the economic damage produced by floods is evident.

Table IT-4: Some of the breaches developed during the All Saints Flood in 2010.

River/channel	River basin	Triggering mechanism	Breach width (m)
Tesina Padovano	Bacchiglione	overtopping	35
Timonchio (1)	Bacchiglione	overtopping	90
Timonchio (2)	Bacchiglione	overtopping	50
Roncajette	Bacchiglione	soft-hard structure transition	40
Frassine	Agno - Guà - Fratta - Gorzone	rapid drawdown + animal burrows (?)	150

The main cause of the flood was the heavy rains that hit in particular the mountain and Piedmont area. Here a total of 300 mm (average) and 500 mm (local peaks) dropped. In many areas the values exceeded the rain with a 50-year return period. Rain was accompanied by Scirocco wind, which blowing on the coast made the tide rise above both the seasonal average and historical data making it difficult for the rivers to drain into the sea. The Scirocco wind also increased the freezing level causing liquid precipitations to occur at higher levels and snow melting. At more than one point the river levels were higher or close to those recorded in 1966, which was the largest flood event since the river network has assumed the actual configuration and one of the most dramatic floods of the past century. The combination of heavy rain and Scirocco wind was also fatal in 1966.

Secchia River (Emilia-Romagna), January 2014
A levee failure occurred along the Secchia River, Northern Italy, on 19 January 2014. In response to this failure, immediate surveillance of other levees in the region led to the identification of a second breach developing on the neighboring Panaro River, where rapid mitigation efforts were successful in averting a full levee failure. An investigative committee was established by the regional authority. In the Secchia River, by combining the information content of photographs taken from helicopters in the early stage of breach development and 10 cm resolution aerial photographs taken in 2010 and 2012, animal burrows were found to exist in the precise levee location where the breach originated. In the Panaro River, internal erosion was observed to occur at a location where a crested porcupine den was known to exist and this erosion led to the collapse of the levee top. Animals like porcupine, badgers and red foxes, due

to the rapid climate change are migrating from the Apennines to the Po plane and find in the river embankments the ideal locations to dig their dens.

The flood damage has been estimated around 500 million euro. Two years after the event the government has spent 110 million euro to refund damaged industries and families, repair public works and restore and increase flood safety (ANSA news).

Po River basin, Emilia-Romagna, earthquake May 2012
In 2012 an earthquake of magnitude 5.9 hit the area south of the Po river. Significant fractures and deformations occurred in a number of riverbanks located close to the epicenter, causing in turn severe structural damages to large part of the houses and productive activities built on the levee crest. The regional authority promoted an in-depth study which demonstrated that the saturated silty sands in the riverbank foundation had developed significant excess pore pressures and permanent deformations during the earthquake, so that the observed ground effects at the riverbank surface had to be ascribed to lateral spreading phenomena (Tonni, 2015).

Serchio River, Tuscany, December 2009
On Christmas day, two failures occurred in the Lucca province near the town of Santa Maria al Colle, two hours after the peak of the flood had transited, causing the leakage of 1 Mm3 of water. The levee was not overtopped.

The same day a third failure occurred between Nodica and Migliarino, at a location that had suffered from other failures in the past. The breach reached a width of 160 m. Before the breach developed, piping was observed to occur through the embankment (Figure IT-8). A leakage of 27.6 Mm3 inundated an area of 13.5 km2 with an average water height of 2 m.

Figure IT-8: Breach initiation along the Secchio River in 2009.

An extensive investigation, including CPT tests with a mini cone, geophysical tests and laboratory classification tests, was undertaken by the University of Pisa to understand the causes of the failures and define methodologies for levee characterization and assessment. The study highlighted how the full saturation of the embankments, reached after two subsequent flood events and depriving the soil of the resistance provided by the partial saturation condition, was more determinant than the actual transited flow. Indeed the same embankments had survived in the past even more severe floods.

During the same flood event another levee collapsed in Tuscany., along the Ombrone Pistoiese River. Also here the failure was attributed to internal erosion.

Discussion

The failure of the Frassine River levees offers an example of the problems that can arise at the reconstruction of a breached levee. In that case, the emergency closure, made discharging jersey blocks and boulders in the current, was subsequently clogged in its central part by means of cement grouting. Moreover, a jet-grouting (suspended) cut-off was built in the levee foundation. During the following flood events, localized seepage occurred through the embankment and sand boils appeared at the landside, showing not only the inefficacy of the intervention but also that there was a high piping potential at that location. The piping potential had probably increased after the top soil layer at the landside had been removed by the current during the flood. The problem was eventually addressed, building a toe drain.

Animal burrowing is considered a big threat for dike safety. Burrows are particularly dangerous for the stability of small levees, where they extend for large part of the cross-section. The burrowing activity of muskrats is jeopardizing the stability of roads and paths built on top of the minor levees. Recent levee improvements generally include the installation of a double twisted steel wire mesh to prevent the burrowing activity.

The Authority for the Po River Basin (Autorità di Bacino del fiume Po, 2014) mapped the historical breaches which have occurred along the Po River, including the triggering mechanism. The atlas also include the location of paleo-channels. Such maps are very useful for planning levee improvement works and emergency operations during flood events.

8.4 Legislation and governance in Italy

8.4.1 Implementation of EU Regulations

In 1989 (L. 183/1989) Basin Authorities were established, to perform actions aimed at the defense of the ground and underground resources and at the rehabilitation, use and management of the water resources, independently on the administrative subdivisions. 7 national authorities and 13 inter-regional authorities were established. In addition, every region was entitled to establish Basin Authorities of regional interest.

In 2006 (D. Lgs. n. 152/2006) the national territory was divided into 8 hydrographic districts. In every district the District Authority was established, with the role of planning the actions for the hydrogeological protection, the creation of hazard and risk maps, the safeguard of the water resources and the aquatic environments.

Since the Ditrict Authorities were not defined yet – and still are not - , in 2011 (D. Lgs. n. 219/2011) the national Basin Authorities were designated to coordinate, at district level, the production of the planning tools required by the so-called Flood Directive (European Directive 2007/60/EU), transposed by the national law D. Lgs. 49/2010.

Some of the principles in the directive had already been anticipated by L. 183/89 that has created the Basin Authorities. The Art. 17 of the law indeed introduced the Basin Masterplan (Piano di Bacino). The planning tools were further oriented towards the hydrogeological hazard by the introduction, after the catastrophic Sarno landslide, of the Masterplan for the Hydrogeological Framework (Piano stralcio per l'Assetto Idrogeologico - PAI) (D.L. 180/1998, DPCM n.29/1998 and D. L. 279/2000). The PAIs represented the starting point for the application of the Flood Directive.

Italy did not undertake the preliminary flood risk assessment required by the directive, since this information was already available in the PAIs.

For the drafting of the flood risk maps the D. Lgs. 49/2010 left the districts free to choose the event probabilities within the following ranges:

- 20≤ T ≤50 years (frequent floods - high probability, P3),
- 100 ≤ T ≤200 years (infrequent floods – medium probability, P2),
- 200 < T ≤500 years (rare, extremely intense floods – low probability, P1),

where T is the return period. The choice was generally made in accordance with the return periods that each Basin Authority had adopted for the preparation of the PAI. The Eastern Alps district adopted probabilities of 1 event in 30, 100 and 300 years, while the Po district adopted different probability values for different environments: main rivers, other rivers in mountain and hill areas, other rivers in the plain area, coastal areas and lake areas.

The law did not force the districts to analyze the effects of a levee breach in the first cycle of assessment (2013). The Po district postponed this activity to the next cycle of assessment (to be done after 6 years). On the contrary, the Eastern Alps district created the flood risk maps assuming that when the water level reaches 0.80 m from the levee crest, than a breach can develop. The size of the breach is given by an empirical correlation with the height of the levee that has been extrapolated from past events occurred in the area (Rusconi et al., 2002).

Flood risk management plans (Piani di Gestione del Rischio Alluvione - PGRA) have been produced and approved. The next phase is the harmonization between PAIs, which remain the compelling tool for urban planning, and PGRAs, which address the management of the flood. The Po district has already started the process introducing a modification to the implementation rules of its PAI, that take into account the new information contained in the flood risk management plan (Variante alle Norme di attuazione del PAI).

8.4.2 National legislation

The binding legislation for levee design is the D.M. 14 gennaio 2008: Norme Tecniche per le Costruzioni [Technical rules for constuctions], which is the code that rules the design of most civil structures and is based on probabilistic design. No specific legislation for levees is available.

National dam legislation, D.M. Infrastrutture e Trasporti 26 giugno 2014: Norme tecniche per la progettazione e la costruzione degli sbarramenti di ritenuta (dighe e traverse), does not apply to levees.

For dams lower than 10 m or with reservoir volume less than 1 million cubic meters the relevant authority decides case by case if the dam legislation or only the technical rules for constructions must be followed.

Legislation concerning planning, governance and flood emergency management is described in Sec. 4.1, 4.3 and 6 respectively.

8.4.3 Governance

Hydraulic structures are classified into 5 categories according to the Royal Decree n. 523/1904 (modified by L. 774/1911). The classification is based on the protected assets rather than on the construction features of structures to be classified.

- Category 1 includes the structures aimed at protecting the course of rivers that delimit the national borders.
- Category 2 includes the structures along leveed rivers when they protect relevant interests involving an entire Province. It includes the levees of the main national rivers.
- Category 3 includes the structures aimed at protecting railways, roads and other structures of public interest, as well assets owned by the State, provinces and municipalities. The structures preventing floods that can produce relevant damage to the territory and the residential areas of one or more

municipalities or can be a threat for agriculture or health are also included. Category 3 includes the largest amount of structures after category 2.
- Category 4 and 5 include the remaining structures.

The structures of category 1 were - and currently are - administrated by the central government.

The structures of category 2 had to be declared belonging to the category by a specific law and were administrated by the government by means of the peripheral offices of the Ministry of Public Works, mostly the Genio CivileOffices. The structures of category 3 were built by the government but maintained by hydraulic consortia. The structures of category 4 and 5 were built and maintained respectively by hydraulic consortia and municipalities.

The decree 523/1904 also established the minimum distances from the levees for plants (4 m) and excavations and buildings (10 m). It also reminds that the cut of the levees (often executed to protect the downstream areas from flooding) is considered a felony to be punished according to the penal code.

Special local authorities entitled to the administration of the levees were the Water Magistrate of Venice and the Po Magistrate. The first was instituted in the 16th century to monitor the safety of the Venetian lagoon system and was abolished in 2014. Its competences were transferred to the Provveditorato interregionale delle opere pubbliche per il Veneto. The Po Magistrate was instituted in 1956 and was substituted in 2003 by the Agenzia Interregionale per il fiume Po [Inter-regional Agency for the Po River] (AIPo).

Italy is currently divided into 20 regions and 107 between provinces and metropolitan cities. From 1998 (D. Lgs. n. 112/1998, art. 89) all the functions connected to:
- the design, construction and management of every type of hydraulic structure,
- small dams (lower than 15 m or reservoir volume less than 1 million cubic meters),
- water policy and emergency intervention

belong to the Regions. Every region administrates the hydraulic structures through agencies that differ from one to another region.

For instance, the following scheme is adopted by the Veneto Region.
- For the principal hydrographic network:
    - the planning and financial administration of the interventions is done directly by the Region through its section Direzione Difesa del Suolo;
    - the interventions are executed by the Project Units of the Genio Civile (U.P. del Genio Civile), which are nearly one per Province.
- For the minor network:
    - the portion in the compounds of the Land Reclamation Consortia (Consorzi di Bonifica) is administrated by the consortia;
    - the portion in the mountain area is administrated by the Regional Forestry Services (Servizi Forestali Regionali) and the Project Unit Forests and Parks (U.P. Foreste e Parchi).

In the Emilia-Romagna Region (Po district) the competences of the Genio Civilewere first transferred to the Basin Technical Srevices (Servizi Tecnico di Bacino) and have been recently assumed by the regional Agency for the territorial safety and the civil protection (Agenzia regionale per la sicurezza territoriale e la protezione civile).

8.5 Guidelines and good practices

- Guidelines, and further integrations, adopted by the relevant authorities for the Po River to rule the design and construction of levees and levee improvements:

- Ministero dei lavori pubblici - Direzione generale delle opere idrauliche (1873) “Circolare 12 febbraio 1873, n° 3651/2200”.
- Circolo Superiore di Ispezione del Po (1952) “Circolare 25 Luglio 1952 per la sistemazione delle arginature di Po e dei suoi affluenti”.
- Magistrato per il Po (1998) “Linee guida per l’esecuzione degli interventi di adeguamento delle arginature di Po sia in corso di esecuzione che di progettazione”.
- Agenzia Interregionale per il fiume Po (2007) “Integrazione delle Linee guida per l’esecuzione degli interventi di adeguamento delle arginature di Po sia in corso di esecuzione che di progettazione”.
- Università di Brescia, Napoli e Roma (2010) “Analisi del comportamento e degli interventi di protezione idraulica delle arginature in materiali permeabili dell’alto corso del Po: Rapporto finale”.

Recently released documents are:

- Rete professioni tecniche coordinate CNI (2015) “Linee guida per la valutazione preliminare della qualità dei progetti per la difesa dalle alluvioni, per la prevenzione dei dissesti sulla rete idrografica e per la difesa delle coste [Guidelines for the preliminary evaluation of the quality of the projects for flood protection, prevention of instability of the hydrographic netstructure and coastal protection]”, http://italiasicura.governo.it/site/home/news/documento608.html

- #italiasicura (2016) “Linee guida per le attività di programmazione e progettazione degli interventi per il contrasto del rischio idrogeologico [Guidelines for the planning and design of structures against hydrogeological hazard]”, http://italiasicura.governo.it/site/home/news/documento611.html. They recall the principles stated by the Flood Directive.

The Italian Geotechnical Association (AGI) has recently undertaken the drafting of national guidelines for levee design.

8.6 Common practices during Levee Life Cycle

8.6.1 Inspection of levees and safety assessment

No regular inspection and safety assessment is prescribed by law.

The Authority for the Po River has assessed the sensitivity of the Po levees to piping, slope instability and seismic hazard (Autorità di Bacino del fiume Po, 2014a) and overtopping (Autorità di Bacino del fiume Po, 2014b). The seismic assessment of about 90 km of embankments located in the area with higher risk (between Boretto, in Reggio Emilia Province, and Ro, in Ferrara Province) was directly financed by the government.

8.6.2 Flood event management

The Royal Decree n. 2669/1937 prescribed the subdivision of the watercourses in reaches for patrolling purposes. Each reach was given into custody to a hydraulic official, which had to travel it completely once a week. The official was assisted by hydraulic guardians, each one responsible for a sub-reach and in charge of measuring the water levels both in peacetime and during flood events. The official and guardians also had to watch the execution of construction/repair structures from beginning to end. Hydraulic officials and guardians were therefore the custodian of a very detailed knowledge of the levees. Nowadays the invested public resources are not sufficient to afford the personnel required for a patrolling as continuous and careful as it used to be in the past.

Besides the regular patrolling, the Royal Decree n. 2669/1937 also disciplined the Flood Service (Servizio di Piena), that was in charge of the officials of the Genio Civile, which operated with the help of the hydraulic officials and guardians.

The new legislative reference for the management of the flood events is the Direttiva PCM 27 Febbraio 2004. It gives indications about "the national and regional warning system for the hydrogeological and hydraulic risk with Civil Protection purposes". Regions are identified as the Authorities of Civil Protection responsible for the warning and the management of the flood events.

The Authorities of Civil Protection make use of the structures established by the DPCM, among which the most important is the Decentralized Functional Center (Centro Funzionale Decentrato – CFD) and the Hydraulic Local Presidio (Presidio Territoriale Idraulico).

The Decentralized Functional Center has the following tasks:
- collection, elaboration, filing, and validation of data from the area of jurisdiction;
- integration and interpretation of physical data and information produced by predictive models; real-time update of predictions on the basis of the evolution of ongoing events;
- evaluation of the level of criticality expected in the warning zones on the basis of predefines thresholds.

The Hydraulic Local Presidio checks the conditions of the levees, monitors the water levels during critical events and is in charge of the first emergency interventions according to L. 225/1992, which establishes the National Service of Civil Protection. The presidio can be of regional, provincial or municipal level.

L. 100/2012 establishes that all the municipalities must be equipped with a municipality emergency plan, which covers a number of risks including flood risk. Indeed the first actions to face an emergency must be undertaken at the local level. The mayor is the most important authority of Civil Protection at the local level. To date, a significant number of municipalities have not produced a municipality emergency plan. When the municipality cannot react to the emergency with the means at its disposal, the higher levels are activated by means of integrated actions: from the province to the region, up to the central government.

The national state of emergency is approved by the cabinet. The request can be made by the president of a region. The maximum duration is 90 days plus additional 60 days upon approval of the cabinet. The state of emergency allows issuing decrees that derogate from the law in force.

8.7 Critical knowledge and data gaps; critical research needs

No information provided

Interaction between levees and dams

The directive DPCM 27 Febbraio 2004 establishes that the authority in charge of the management of the flood events must ensure, by controlling the discharges, the maximum detention of the flood. In addition, the fluxes released must not be dangerous for the watercourse reaches downstream of the detention structure as well as compatible with the emergency plans of the provinces involved in the event.

By means of specific studies, the reservoirs that could be helpful for the detention of the flood, and thus for the mitigation of the flood risk must be identified. For such reservoirs a flood routing plan must be provided. The plan can be either static or dynamic and must take into account:
- the mitigation of the effects downstream of the reservoir,
- the safety of the detention structure,

- the need to use of the volumes retained (f.i. drinkable water supply).

It is important to remind that the peak flow mitigation implies that the levees are exposed to high water levels for a longer time and must therefore be reinforced and /or waterproofed.

The directive DPCM 8 luglio 2014 gives indications about the activity of civil protection in basins including large dams.

8.8 Summary of key facts

Features of the levee system

- Po River: 650 km, 141 tributaries. Po District: 2300 km of levees of category 2.
- Eastern Alps District: Adige rive: 410 km + 5 main rivers flowing into the Adriatic sea. 6300 km of levees of all categories.
- The levees in the medium and lower course of the Po and Adige river have wide cross sections reinforced across the years, the other rivers in northern Italy have much narrower cross sections. The construction materials mostly depend on the geological context: mountain valleys, upper plain or lower plain.

Residual risk

For a medium probability event, 8% of the national territory would be flooded. 6 million people live In this territory (10% of the population) and there are 600 000 productive units.

Recent failures

- Veneto Region, 2010: 9 levee breaches, 426 million euro damage. Failure mechanisms: overtopping, rapid drawdown, soft-hard structure transition.
- Secchia River, Po district, 2014: 500 million euro estimated damage. Failure mechanism: instability promoted by animal burrows.

Key players

- Planning: District Authorities; however, since these are not established yet, the Basin Authorities of national relevance coordinate the planning at district level.
- Administration and management of flood defenses: Regions + operative structures as: Genio Civile, Civil Protection Agencies, Land Reclamation Consortia, Mountain Basins etc.
- Administration and management of flood events: Regions, through operative structures as:
    - Decentralized Functional Centers, with function of data analysis, formulation of scenarios and communication of alarms;
    - Hydraulic Territorial Presidio with function of levee patrolling and first interventions;
    - Other stakeholders, among which dam managers.
- Management of flood emergencies: Regions are the relevant Authorities of Civil Protection for flood emergencies. Municipalities should be provided of an emergency plan, including the actions to take in case of flood emergency. Mayors the most important Authorities of Civil protection at the municipality level. The President of the Region can ask the Prime Minister to declare the national emergency state.

8.9 References

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Section 4

See laws and decrees mentioned in the text. Thay are all available online.

Section 6

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9 The Netherlands

9.1 Facts and figures on levees and flood defences

In the Netherlands, the following types of flood defence are common:

- mostly natural sand dunes along the North Sea coast
- levees along rivers, lakes and part of the coast (often referred to as 'dikes' or 'dykes')
- dams (similar to levees, but generally across rather than along the water, separating two large water bodies)
- storm surge barriers (similar role as dams, but not levee-like, instead they are moveable hydraulic structure)
- hydraulic structures (sluices, etc.)
- temporary flood barriers (in some urban areas)

Please note that the above typology might be somewhat coloured by the Dutch context.

An important distinction is made between primary flood defences and secondary or regional flood defences. Primary flood defences protect against floods that are large enough to cause life risk and major economic damage; they have a safety standard referred to in National Law. Secondary flood defences merely protect against local or regional damage and have a safety standard from the regional province. Some of the smallest levees even have no explicit safety standard, such as the summer levees which make sure that river flood plains normally only inundate during the winter season.

Figure NL-1: Rural lake-side levee during storm, with waves well above 1 metre (rubble-stone waterline berm and lower half of slope with placed stone partly submerged).

There are over 3500 km of primary flood defences in The Netherlands. A small fraction of these consist of dunes (nearly 300 km), dams (order 100 km), an even smaller fraction of moveable flood barriers (along some city waterfronts) and of storm-surge barriers. In addition there are nearly 1500 hydraulic structures that are considered as a primary flood defence.
The length and number of regional flood defences is not exactly known, but most probably in the order of 5 times as large as the length and number of primary flood defences, with a very dense network of

secondary levees in the low-lying polder area (often even below sea level) in the West and partly also the North of the country.

Figure NL-2: Broad urban levee in Lelystad with flotsam from recent storm (offshore breakwater sheltering the levee not visible).

The main difference between primary flood defence levees and regional or secondary flood defence levees is in their size and revetment, but otherwise they are quite similar.
Both are usually constructed using locally available clay, sand or (mainly in the case of secondary levees) peat, and both often have slopes in the order of 1:3. Steeper slopes tend to become unstable when saturated and are becoming less common, unless pile walls are used for support; generally intrinsic safety is preferred over safety provided by drawing down the phreatic line by means such as filters. Especially for primary levees and dams, berms are commonly used to reduce slope instability and piping, but on the outer slope also to reduce wave-runup and wave overtopping.
When sand is used for levees, especially the outward facing top layer generally consists of a clay layer to prevent quick saturation (and weakening) of the sand as well as internal erosion; also a deep layer with partly non-weathered clay has some resistance against wave erosion. Grass revetments are used where possible, but especially primary lake-side and coastal levees often have a placed-stone or asphalt revetment on their outer slopes, which has to resist wind waves with a height of 1 metre up to several metres.
Typical levee heights are up to a few metres for secondary levees, whereas primary levees have typical heights about 6 metres (range roughly 3-10 metres). Estuary dams have even larger heights, not as much when referenced from sea level, but rather measured from toe to top since many estuary dams are built across tidal channels which may be 10 to over 40 metres deep. The latter type of dam is also included in the ICOLD dam register.
Roughly one-third of primary levees is along the branches of the Rhine and Meuse rivers, another one-third along the estuaries, and the remaining one-third along large lakes and along the coast. Typically, levees along the rivers have to deal with several days of high water levels during river floods, but not with excessive wave loading. By comparison, coastal and lake levees usually have rather short periods (order 1 day) with strong wind-setup and heavy wave-attack as a result of severe storms. In the estuaries, both situations may play a role.

9.2 Protected value, safety standards and flood risk

Without levees, dunes and other flood defences, nearly 60% of the Netherlands would be prone to flooding. This includes the population and economic centres of the country including the cities of Amsterdam and Rotterdam, so that about 70% of our population and economy is prone to flooding. This implies that without flood protection, about 12 million people would be prone to flooding, about

400-500 billion of economic production, and about 1,5 trillion Euro of building property, given the Gross Domestic Product is about 660 billion Euro/year and the private plus company building property value of over 2 trillion Euro (latter two numbers from http://statline.cbs.nl)

The safety standard of all primary flood defences used to range from a probability of 1/10000 per year for Central Holland, to 1/1250 per year for low-lying inland areas which are only prone to river floods, and 1/250 per year for the upper Meuse valley. So the most stringent safety standards have been for the most densely populated areas prone to coastal flooding (little warning time, salt water inundation), whereas the standard become more lenient for rivers (more warning time). These safety standards are related to the probability of water levels (or more generally hydraulic loads) that flood defences must safely (with order 90% probability) must withstand. In the last 2011 assessment round, nearly two-thirds of the levees (and a somewhat smaller fraction of the hydraulic structures) satisfied the safety standards.

Meanwhile, more differentiated risk-based safety standards have been implemented. These standards express the probability of flooding due to a breach in a given stretch of levees, and are therefore not easily comparable with the former safety standards. The allowed flooding probability is based on personal risk targets (less than 10^{-5}/yr mortality probability on a given location) including evacuation possibilities, or on cost-benefit considerations if these are more critical. Safety standards are also more stringent when a breach will severely affect critical infrastructure, or cause massive damage or massive life risk.

The new safety standards (in terms of flooding probability) typically range from 1/100000 per year for the city of Rotterdam and parts of the Western Scheldt and 1/30000 per year for many other high-risk areas along rivers, lakes and population centres, to about 1/3000 per year for many other levee stretches and 1/300 per year for the upper Meuse valley (Slomp et al, 2016).

The report "Eindrapportage VNK"(www.rijksoverheid.nl/documenten/rapporten/2015/01/16/eindrapportage-vnk-de-veiligheid-van-nederland-in-kaart) gives an impression of the actual flooding risk. Economic risk is strongly variable and highest for some urbanised hotspots, where the economic risk may exceed 5 MEuro per km per year; as a region, the Betuwe region between the "Nederrijn/Lek" and "Waal" branch of the Rhine stands out, as well as the Beveland area along the Western Scheldt. The Betuwe area also stands out with respect to personal risk (order 10^{-4} mortality risk per year), although many areas (especially deep polders) along the rivers, major lakes and Wadden Sea coast do not yet satisfy the intended risk target of 10^{-5} per year.

Besides overtopping of levees, piping of river levees (internal erosion through sandy underground layers) appears to be the main contributor to this risk.

On a national level, actual flood probabilities (including the present levee protection) are highly variable, but most often roughly in the order of a 1/500 year probability. This results in a flood risk equivalent to on average a few dozen victims per year (for all of the Netherlands) and an expected damage of over 500 million Euro per year. If a flood were to occur, the damage would be much larger, but luckily, floods and levee breaches are a rare phenomenon in the Netherlands. One can also note that the actual expected risk is several orders of magnitude smaller than the protected value mentioned in the beginning of this section.

Still, the above safety assessment results were one of the triggers for major levee reinforcements which are currently underway, and also for the adoption of a more risk-based set of safety standards as described above.

9.3 Recent major floods and (near-)failures of levees

In former centuries, levee breaches due to coastal surges and river floods occurred quite regularly, and could cause thousands of casualties. In the past ice jams/dams the contributed to flooding.

The first major flood of the 20th century occurred along the Zuiderzee estuary, probably due to an order 1/100 yr storm surge plus moderately high river discharge , causing damage and minor breaches along the coast and the IJssel-Vecht river delta, but especially great damage along the Zuiderzee estuary where record water levels were measured. Damage was not as extensive in the Rotterdam – Dordrecht area, even though record water levels were measured there. In fact, there were marked spatial variations in water level return period (order 30-300yr) depending on whether surge peak coincided with high tide. The worst hit were the regions of Waterland and the island of Marken, both near Amsterdam, causing not only extensive damage but also dozens of casualties. This disaster was one of the triggers for building the Afsluitdijk, and also to establish the SVSD Storm Surge Warning Service. The levees in the worst hit area were often peat levees with rubble (and rubble roads on top), where the rubble allowed for easy infiltration followed by slope instability (statement of Reigersberg, Source: Noord Hollands Dagblad special issue 9 Jan 2016); since then no roads were built on top of levees in that region. In the SE part of the Zuiderzee estuary, many small breaches due to overtopping and inner slope saturation and failure occurred, somewhat similar to the type of levee failure in the 1953. More information can be found on:

- https://nl.wikipedia.org/wiki/Stormvloed_van_1916;
- http://historiek.net/stormvloed-van-1916/5841/#.VrSo3JckpyE
- http://www.kennislink.nl/publicaties/1916-de-watersnoodramp-die-nederland-veranderde
- http://repository.tudelft.nl/view/hydro/uuid%3A3ff3fdab-003b-477e-bad3-2d89361420d3/

The 1926 river floods occurred when an early winter was followed by a wet thaw, and produced the highest discharges in recent history with roughly 1/150 yr recurrence time. Several small levee breaches occurred along the Rhine, Meuse and Vecht river branches , related to both piping (mainly along Rhine branches), stability and overflow problems. Major levees breaches occurred near Cuijk and Land Maas & Waal, and a sudden sudden piping breach near the village of Zalk near the town of Kampen, along the IJssel river branch; a few people fell victim to these floods. See also:

- http://repository.tudelft.nl/view/hydro/uuid%3A5aee4476-3245-42da-a9aa-5807f2b77b6e/
- https://dute.home.xs4all.nl/overstroming%201926.htm

The worst storm surge in recent history took place in early 1953, with massive overtopping and even overflow of many levees in the Southwest of the country. Many cases occurred with slope stability failure, especially for slopes steeper than 1:3. As opposed to the 1916 floods, on this occasion the levee roads (especially tarmac roads) reduced damage or even prevented failure. Also, the presence of foreshores often helped to prevent a real levee breach. Despite this, 1835 casualties occurred and 20000 people got homeless. This major disaster was the trigger to develop safety standards, and was also the trigger for the design and construction of the now world-famous Delta Works. See also:

- https://en.wikipedia.org/wiki/North_Sea_flood_of_1953
- http://repository.tudelft.nl/view/ir/uuid%3A0e28dfd8-4e67-4267-a443-54b74a062bcb/
- http://repository.tudelft.nl/view/hydro/uuid%3Ab5ef3731-92b0-4404-8dfc-8ab7f63619ae/

Few people know about the sudden flooding of the Tuindorp-Oostzaan district in Amsterdam, in January 1960, so that the flood became a 'forgotten disaster'; a broken water pipe in the levee may have been the cause. Despite 2m inundation depth of icy water, there was just one victim that might be directly ascribed to the flood. See also:

- http://www.historischarchief-toz.nl/watersnood_1960.htm
- https://www.historischarchief-toz.nl/presentatie-boek-de-vergeten-watersnood/
- http://nationaalbrandweerdocumentatiecentrum.nl/wp-content/uploads/2015/01/Overstorming-Tuindorp-Oostzaan-deel-1.pdf
- http://www.npogeschiedenis.nl/nieuws/2010/januari/50-jaar-geleden-Tuindorp-Oostzaan-onder-water.html;

In late 1993 and early 1995 major river floods occurred again, this time roughly with 1/50yr discharges. No major levee breaches, but there may have been some minor ones such as along the small river Dommel near Bossche Broek. The 1995 flood brought an imminent threat of piping failure during 1995 flood, which resulted in a massive evacuation from Betuwe and also from parts of Limburg, with 200000 people evacuated. This event was the trigger for the Flood Defence Act (safety standards implemented by law, regular safety assessments and reinforcement rounds) and also for the Room the River floodplain restoration project.

In August 2003, a peat levee failed after a prolonged period of drought, causing 30 cm of water on the street in the village of Wilnis. This was a spontaneous night-time failure of a dried-out peat levee, causing the levee to “float” away. It was a trigger for peat research, and also for measures (water spraying campaigns) to prevent excessive drying-out of peat-levees during spring and summer droughts. See also:

- http://library.wur.nl/WebQuery/hydrotheek/1709445
- http://www.hansmiddendorp.nl/dijkdoorbraak-in-wilnis-in-2003/
- http://files.kennisplein.intranet.minienm.nl/2/5/251123/Onderzoekers_ontrafelen_raadsel_van_Wilnis_().pdf (see also land & Water 44, p 26-27)

In 2004, a failing water supply pipe caused serious damage to a canal levee near the village of Stein, once again (after the 1960 event) an indication that pipe failure risks also need to be considered. See:

- https://www.onderzoeksraad.nl/nl/onderzoek/386/leidingbreuk-veroorzaakt-dijkverzakking-stein-27-januari-2004

Most but not all failure occurred during flood situations: exceptions were the 1960 failure and 2004 near-failure due to failing water supply pipes, and the 2003 peat levee failure due to drought.
Storm surge failures were typically caused by overtopping/overflowing in combination with slope stability failure, either due to too much infiltration (rubble materials in 1916 levees and levee-top roads/tracks) or due to saturation and failure of steep slopes.
For river floods, failure and near-failures were often due to piping, which is also illustrated by the fact that many historical levee breach locations (recognisable by the ponds at the erosion hole [“wielen”] and the levee curving around those ponds) coincide with underground sand strips.

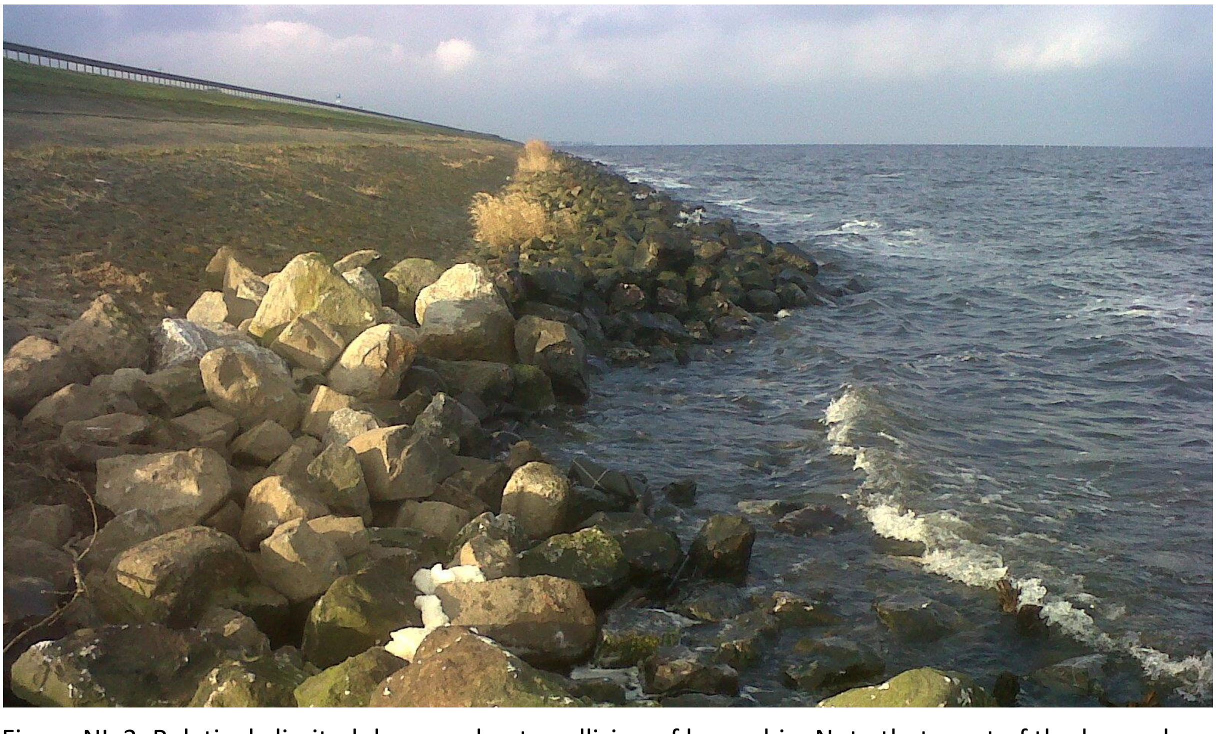

Figure NL-3: Relatively limited damage due to collision of large ship. Note that most of the levee slope has either stone or asphalt revetment, with grass only near the crest

9.4 Legislation and governance in the Netherlands

9.4.1 Implementation of EU Regulations

Requirements of the EU Floods Directive are mainly satisfied through the National Legislation as described in the section(s) below. The Flood Risk Management plans as described by the EU Floods Directive can be found at www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/eu-richtlijn/overstromingsrisico/ (Dutch version only). The plans mainly give an integrated description of Flood Risk Management actions and their background; protection through levees is only one aspect of this. Chapter 7 of these FRM plans does not discuss levee management in detail, but rather gives a description of legislation (as described in the paragraphs above) and policy plans & targets.In addition the FRM-plans gives various hazard maps for three probability levels (yearly, rare, extremely rare).

9.4.2 National legislation

In the Netherlands, the same legislation generally applies for levees and dams with a flood protection function, the main difference being that for some storm surge barriers, an additional target is set for the reliability of closure, and that for some dams flood risk from either side of the dam has to be considered, rather than just from one side. Details of the legislation are given in the Dam legislation Report of the ICOLD European Club, so only the main features are given here.

In the context of levees, the Water Act http://wetten.overheid.nl/BWBR0025458/2017-01-01 is the most relevant, although environmental legislation (Environmental Impact Assessment procedures etc.) is equally important in the case of construction. The Water Act contains provisions related to Flood Risk Management and to Water Management in a general sense. By and large, the Water Act contains the following elements:

1. Chapter 1 – General provisions, mainly definitions
2. Chapter 2 – Aims and Standards: refers to general aspects of the safety standards and the safety assessment, hydraulic boundary conditions for safety assessment and guidelines for design,
3. Chapter 3 – Roles of different organisations involved in water and flood risk management, and provisions related to flood warnings
4. Chapter 4 – Policy and implementation plans
5. Chapter 5 – Construction, operation and maintenance of water works
6. Chapter 6 – Water permits and related issues
7. Chapter 7 – Financial issues
8. Chapter 8 – Law enforcement
9. Chapter 9/10 – various issues
10. Annex I + II: Dike rings and safety standards for those dike rings

The Water Act (2009) integrates a range of former water-related legislation including the Flood Defences Act of 1996. In relation to water defences, the Water Act contains an Annex with an overview of primary water defences, and sets conditions for the primary flood protection structures in terms of the responsibilities of the authorities involved, the safety standards, the regular safety assessment, the procedure for reconstruction of structures and the framework for financing of reconstruction and maintenance. The contents of the Annex has recently changed because of a safety standard update (standards in terms of flooding probabilities rather than water level exceedance probabilities, and referring to dike stretches rather than full dike rings to allow for differentiation).

Primary water defences which directly protect the hinterland, are directly assigned a safety standard from the Water Act. For (mainly estuarine) dams which separate two water bodies, it generally has been not the Water Act itself but the underlying regulations which assign the safety standards.

The Water Act prescribes a safety assessment every twelve years. The instruments for safety assessment are provided by the ministry and are known as the “WBI” Legal Assessment Instrument;

the WBI consists of hydraulic load boundary conditions (so-called “HB”)and guidelines for safety assessment. The local water boards are to report the results of the safety assessment to the ministry (and the Inspectorate on Environment and Transport). In turn, the ministry reports to parliament. Levees which do not pass the safety assessments due to changes in the safety standard or the “WTI” instrument and are eligible for (50%) subsidies for reinforcement.
Besides in-depth safety assessments every 6/12 years, there are also regular maintenance actions and frequent visual inspections, the latter especially around flood events.

The Water Act also prescribes that the ministry shall issue warnings to local water boards when water levels exceeding so called alarm levels are expected. Local water boards are obliged to prepare emergency plans and train their personnel and equipment regularly. However, the responsible parties for general calamity management (rather than actions to preserve a levee) are not the water boards but local communities, Provinces and the Ministry of Safety and Justice.

9.4.3 Governance

The primary flood protection structures are mostly managed by local authorities, regional water authorities formally called water boards. The water boards, democratically elected bodies with the equivalent status as a municipality (presently about 22), have the authority to raise taxes on the inhabitants of the low lying polders for maintenance and construction of the structures.
The national Inspectorate of Environment and Transport has the supervision over all aspects of Flood Risk Management by the water boards.
The national government, more specifically, the Ministry of Infrastructure and Water Management, has the overall responsibility for Flood Risk Management in the Netherlands, both for policy, policy implementation and inspection. The ministry issues safety standards for primary flood defences, and the hydraulic boundary conditions associated to the safety standards, and makes sure guidelines for design, safety assessment and maintenance are made available, whilst promoting and providing significant funding for research in the fields of dams and flood protection. The ministry is also responsible for environmental legislation.
The public body in charge with the policy implementation and other actions on a national level is the Directorate General of Public Works and Water Management, also known as “Rijkswaterstaat” (RWS). As opposed to levees, most large dams (especially the estuarine storm surge barriers) in the Netherlands are owned and maintained by Rijkswaterstaat, which also maintains the coastline by sand nourishment.

Flood protection in the Netherlands is a public matter. The majority of the flood protection structures is owned by the local water boards or the ministry. Private ownership of flood protection structures, however, is possible, but the owner has to comply with regulations issued by the local water board or the ministry. Maintenance responsibility and (sometimes private) ownership may be separated, but this situation is mainly restricted to small (and secondary) structures, rather than large levees or dams.

9.5 Guidelines and good practices

Through the Water Act, the ministry recommends guidelines for the design, construction and maintenance of flood protection structures. Where necessary, the guidelines refer to specific building codes. The guidelines are to be used as a general framework and may be adapted to specific local circumstances. The guidelines are prepared in co-operation with local water boards, consultancies and research institutes. For Quality assurance the parties involved co-operate in the framework of the Expertise Network on Flood Risk Management ENW who advise on all guidelines (www.enwinfo.nl) ; note that ENW is the official flood risk management advisory committee, appointed by the Dutch government. The final responsibility remains however with the central government. A major updating and restructuring action of the above guidelines is now underway.
The main types of Guidance Document are:

- Framework for Duty of Care ("Kader Zorgplicht"); see http://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/zorgplicht/ . This comprises a broad range of topics such as juridical document requirements, reporting requirements, data/information/knowledge management, regular inspection & maintenance & operation, permits and oversight over permits and calamity management
- "WBI": Instruments for periodic safety assessments as prescribed by law
- "OI": Design instruments for design and reinforcement of levees and flood protection structures
- Various guidelines from Expertise Network on Flood Risk Management, www.enwinfo.nl.

Details and web links are given in the references section of this chapter.
Finally, it is noted that there is a strong reliance on dedicated national guidelines; the International Levee Handbook is not yet commonly used, and this applies even more strongly to the ICOLD-Bulletins.

9.6 Common practices during Levee Life Cycle

It is hard to report on such a wide range of topics, so just some observations and general trends are given:

- Given the huge protected value, the Netherlands requires a very high protection level, which in turn results in an extreme reliance on flood protection through levees etc.
- This also results in a very strong reliance on modelling approaches rather than observational approaches or engineering judgement, even though it is recognised that accurate (geotechnical) modelling is only possible through thorough ground investigations.
- The above aspects, together with the fact that the Netherlands has a small Inspectorate with large responsibilities, also result in a strongly standardised approach with explicit (legal) safety standards and guidelines which are strongly recommended by law, if not prescribed.
- Despite the above, inspections are mainly visual (with digital storage tools) and range from weekly/monthly global inspections, to yearly in-depth inspections and 12-yearly quantitative safety assessments prescribed by law. Maintenance has been based on good engineering practices for a long time, but has in recent years become more and more risk-based.
- Real flood events are quite rare in The Netherlands and if they occur, the scale of flooding can be huge. This, and the weather conditions during coastal flooding (major storm!) make disaster management a real challenge.
- Despite the high costs of levee reinforcement (from about 1 million Euro/km for very 'easy' cases to order 30 million Euros in for example complex cases in built-up areas), their investment is nearly always worthwhile, and now supported by safety standards (partly) based on cost-benefit analysis. It is worth noting that the all-in-cost of regular levee maintenance (including inspections and safety assessments) is only of the order of 50000 Euro per kilometre per year, in fact the yearly national budget for upgrading the primary levees and protection structures is larger (360 million Euros)
- More information on storm surge barriers can be found on the site of the international network www.i-storm.org.

9.7 Critical knowledge and data gaps; critical research needs

In 2017, some research agendas were drafted for the WBI2023 project for safety assessment tools and also in the wider context of the National Water and Climate Knowledge program NKWK. Below, just a few of those items are given:

- Uncertainties about the foundations and geotechnical and geohydrological properties of levees are often critical in safety assessments, all the more so because the ground can have strong small-scale variability.
- Properties and effect of physical maxima on extreme value statistics of wind (main driving factor for coast, estuaries and lakes !), river discharges, storm surge and wind waves and earthquake loads, and the associated uncertainties. Alternatives for extreme value distributions based on (too short) measured data sets.

- Improved modelling of internal erosion and piping compared to Sellmeijer, to achieve less conservative approach
- Interaction of failure mechanisms (overtopping and slope instability, etc.)
- Strength of transitions between different types of structure, revetment, etc.
- Modelling (induced and natural) earthquake loads and other vibrational loads (wind turbines, ..) and their effects on levees
- Added value of levee monitoring and remote sensing

9.8 Summary of Key Facts

- About 3500 km of primary flood defence; about 3000 km of levee, typically 3-10 m high (average ~6m); slopes mainly order 1:3, often interrupted with a berm
- In addition about 1500 hydraulic structures as primary flood defence
- 3% along rivers, 30% estuaries, remainder along lakes and coast
- Former safety standards by law: withstand 1/250 to 1/10000 per year water level; nearly two-thirds of defences are OK
- New safety standards by law: 1/300 to 1/100000 per year flood probability; probably more stringent.
- 60% of land and about 70% of population/economy at risk without levees. This is 12 million people or 400-500 billion Euro of yearly economic production, and over one trillion Euro in terms of protected value.
- Present actual protection level about 1/1000 per year, but this used to be less
- 6-7 floods or near-failures in last century, typically during 1/100 yr events. Various causes (overtopping and slope failure coastal levees, piping for levees, as well as failure due to non-flood causes like water supply pipes and drought etc)
- Strong reliance on protection (by levees), and on standardised (and often model-based) approach for safety assessment, design, and to some extent also daily management
- Damage cost is limited due to strong protection, national reinforcement budget is 360 million Euro/yr, regular maintenance spending probably less. Typical cost per kilometre is order 50000 Euro/yr for regular (all-in) maintenance and 1-30 million Euro per kilometre for each major upgrading.
- Safety standards included in law, guidelines referred to in general sense
- strong reliance on dedicated national guidelines; the International Levee Handbook is not yet commonly used, and this applies even more stongly to the ICOLD-Bulletins

9.9 References

R. Slomp, H. Knoeff, A. Bizzarri, M. Bottema & W. de Vries1, 2016, Probabilistic Flood Defence Assessment Tools, Paper 03015 in Proc. FLOODRISK 2016 Conference

An overview of references and weblinks is given below. All weblinks in this chapter were checked and updated by 28 June 2017.

Useful documents on www.helpdeskwater.nl

a. Information on Dutch Water Act (2009/2010, slightly outdated): https://www.helpdeskwater.nl/secundaire-navigatie/english/legislation/
b. Brief brochure on the Water Act (2009), not yet updated: https://www.helpdeskwater.nl/secundaire-navigatie/english/legislation/
c. Relatively recent (2012) though not fully updated overview of Flood Risk and Water Management Policies in the Netherlands – https://www.helpdeskwater.nl/secundaire-navigatie/english/water-and-safety/

d. Booklet describing the main insights from the FLORIS Flood Risk Study, major source of inspiration for the "WBI" Legal [water defence safety] Assessment Instrument, which is now under development: https://www.helpdeskwater.nl/secundaire-navigatie/english/water-and-safety/
e. In Dutch language only:
   i. Current/new version of the "WBI" Legal [water defence safety] Assessment Instrument, used for upcoming safety assessment: https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/beoordelen-(wbi)/
   ii. New safety standards https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/nieuwe-normering/
   iii. Formal design tool "OI2014" to be used for the present dike reinforcement round and References to other/various documents related to design: https://www.helpdeskwater.nl/onderwerpen/waterveiligheid/primaire/ontwerpen-beheer/

Useful documents on www.enwinfo.nl (ENW Guidelines)

a. Overview of Dutch-language publications of ENW: www.enwinfo.nl
b. Overview of English-language ENW publications (no longer available through www.enwinfo.nl, but TU Delft gives some links of older ENW documents), containing the following guidelines (note that there not yet a translation of the "LeidraadKunstwerken" (Guidelines on Hydraulic Structures), which is currently being updated, given –amongst others- the introduction of new European Building Codes (Eurocode):
   1. Fundamentals on Flood Protection: https://www.enwinfo.nl/images/pdf/Grondslagen/GrondslagenEN_lowres.pdf
   2. Guidelines on Sea and Lake Dikes ; https://repository.tudelft.nl/islandora/object/uuid:1d4423db-34ed-4a78-8f36-10bf28d73e9f?collection=research
   3. Technical Report Clay for Dikes ; https://repository.tudelft.nl/islandora/object/uuid:76d7502e-1519-449f-874f-fcd70f12c221?collection=research
   4. Technical Report Erosion Resistance of Grassland as Dike Covering; https://repository.tudelft.nl/islandora/object/uuid:446b0289-dad6-4c87-b8cd-bb81128a5770?collection=research
   5. Technical Report Wave Run-up and Overtopping at Dikes ; https://repository.tudelft.nl/islandora/object/uuid%3Ad3cb82f1-8e0b-4d85-ae06-542651472f49
   6. Technical Report on Sand Boils (Piping) ; https://repository.tudelft.nl/islandora/object/uuid:f6d03006-7744-452e-8ff2-a4914f118184?collection=research
   7. Technical Report on Soil Structures; https://repository.tudelft.nl/islandora/object/uuid:ea6d963d-74f5-425f-9e7b-09b0afc81732?collection=research

10 Spain

10.1 Facts and figures on levees and flood defences

There has been an official inventory of dams and reservoirs in Spain for more than 50 years.. However, there are no official or complete inventories of levees and other structures. River basin districts with more defences usually have a lot of agricultural crops in areas at risk.

For instance, the Ebro River, one of the more important rivers in Spain, has a partial inventory for 225 km along its middle course. This inventory shows that 48% of the river stretches have levees, which mostly defend croplands.

Another example would be the Duero Basin District, where canalised rivers and levees have been studied in an inventory of pressures for the river basin management plan. These studies identified around 10,000 km of heavily modified channels of which at least 7,000km included levees. Similarly most rivers in the upper Guadiana basin district (over 1,000 km) are channelled with levees built with material from the dredging of rivers.

Figure ES-1: Flood event at Ebro river in Novillas, April 2018. Source: elpais.com.

With the implementation of the Water Framework Directive and the Floods Directive, different studies are currently being developed, which will help to establish the actual extent and statusof levees in Spain.

Levees in tributaries and small streams are a moderate size and rarely exceed three metres high. Levees in large rivers have greater dimensions, with maximum heights around five metres.

These levees were originally built out of materials from the river dredging (mainly gravels and sands). When levees were overtopped or eroded, they are usually repaired with similar materials or, in some casesrubble. For this reason, some levees suffer from leakage and other structural problems. Only a few have been well designed and constructed with and impervious core.

Figure ES-2. Levee segment in the Ebro river in Novillas (Zaragoza). Source: MITECO (Spanish Ministry for Ecological Transition).

In most of the water bodies levees protect cultivated areas and small towns linked to agricultural production. Big cities often have a channelled river, in some cases accompanied by levees. Levees are usually located in riverine areas, and only in a few cases in coastal areas.

Levee maintenance is rare and usually limited to improvements in the upper layer of the structure, in order to allow vehicular to travel where there is enough room. These actions are generally carried out by local authorities or users. Major repairs, as well as reinforcement, are undertaken after flood events, when these defence structures have been damaged by the water. Investments required for these works are normally funded by the state or by regional governments.

Figure ES3a: Levee segment in the Ebro river in Torres de Berrellen (Zaragoza). Source: MITECO (Spanish Ministry for Ecological Transition), and, Figure ES3b: Levee segment in the Ebro river in Pradilla (Zaragoza). Source: MITECO (Spanish Ministry for Ecological Transition).

Due to the high variability of the Mediterranean climate, Spain has needed to build more than 1,000 large dams. These usually have multiple uses, mainly water storage for summertime and especially for water during periods of drought. Most of these dams are also important for flood risk mitigation although rarely they are specifically designed only to reduce flooding. Other flood defences are common in many rivers such as dykes and levees, but usually they are not high enough; in addition, their maintenance and security management are not as regulated as those of dams and reservoirs.

10.2 Protected value, safety standards and flood risk

There is no exact Information on protected value available because there is not an official inventory. As already mentioned, levees usually protect agricultural areas and small villages for low return periods, but they may have negative effects when water overflows them.The following table shows estimated figures for existing population in areas at risk of flooding based on hazard and risk maps:

Table ES-1 Population at Risk

Source of flooding	*Estimated population living in areas at risk*	
	Medium probability (100 year-event)	*Low probability (500 year-event)*
Fluvial	1,939,447	2,818,585
Marine	321,372	365,692

Nearly 300 IPPC industries are located in flood zones The total surface of the Area of Potential Significant Flood Risk (APSFR) is about 6000 km2, representing roughly 1% of the surface of Spain.

There is no specific legislation governing levees, dikes or other embankment types. They are designed with the best available technical criteria, but there are no specific requirements.
Neither is there information on residual risk. It is scheduled to start working on these issues with the development of the Flood Risk Management Plans of the Floods Directive.

10.3 Recent major floods and (near-)failures of levees

Floods in Spain can seriously impact on people and cause important economic losses. Although in recent years there has not been major disasters, every year around 10 people die as a result of floods Economic losses are very important, and are estimated at 800 million euros per year, that is, about 0.1% of GDP (for example, every year an average of 200 million euros are allocated to compensate for damage to insured properties).
The safety level of levees in Spain depends mainly on their characteristics and how they have been built: design and materials (strength size, height, impervious core, adequate foundation, compaction, slope protection against erosion, etc.) and execution of works. Llevees protecting towns have gradually been improved over time (both stability and permeability) through specific actions or coincident with repairs after a flood event. Levees protecting agricultural areas, as already mentioned, do not have a planned maintenance.

Therefore, levee failures in Spain are frequent. Overtopping, lack of stability, slope erosion, excessive seepage or internal erosion are usually the main source of problems.

Figure ES-4. Flood event at Ebro river in Novillas, March 2015. Source: iAgua.

Figure ES-6. Example of partial failure in a levee due to an inadequate foundation.

10.4 Legislation and governance

10.4.1 Implementation of EU Regulations

The enforcement of the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (hereafter, the Floods Directive) allows the development of a common framework to reduce losses due to flooding. During the first cycle of the Directive implementation, Spanish authorities have produced flood hazard and risk maps. The Floods Directive was incorporated into Spanish legislation through the Royal Decree 903/2010 on the assessment and management of flood risks. The Government has already approved most of the Flood Risk Management Plans. All information is available at:

Royal Decree: https://www.boe.es/diario_boe/txt.php?id=BOE-A-2010-11184

Floods Directive implementation: http://www.magrama.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/

10.4.2 National legislation

Spain has a detailed legislation on dam and reservoir safety for more than 50 years. Our dams have a broad range of requirements for operational safety, risk classification, emergency action plans, etc. However, in terms of levees, there is no specific legislation for the design, construction, maintenance and safety management.

Since 2008 a royal decree regulates where levees can be located, establishing a clear limitation to the construction of levees too close to rivers: "Except in exceptional cases, levees can only be built in the floodway for protecting existing populations".

With the same objective, some River Basin Management Plans (e.g., that of the Douro River Basin District) include additional requirements to locate levees, so as to coordinate the objectives of the Water Framework Directive with flood risk management.
As already mentioned, dams and levees have different safety legislation. The main rules are stated in the Water Act and in the Royal Decree establishing the uses of the hydraulic public domain.

The Water Act provides the basis for managing the safety of dams and reservoirs, but not levees. In the Royal Decree establishing the uses of the hydraulic public domain, many aspects about water management and rivers are regulated. As for levees, there are only regulations concerning where they can be located.

Therefore, the difference with the dam and reservoir regulation is enormous. Spain has a detailed legislation on dam and reservoir safety for more than 50 years Our dams have a broad range of requirements for safety operation, risk classification, emergency action plans, etc. However, in terms of levees, there is not a specific legislation for the design, construction, maintenance and safety management.

10.4.3 Governance

In general, levees were built by public administrations (e.g. the Ministry of Agriculture, Food and Environment through River Basin Authorities, or Regional Administrations). Their maintenance is mainly performed after flood events. In some cases, levees may be built by other stakeholders, provided that they have the required permissions from the River Basin Authority and, in all of the cases, the required environmental impact assessment.

The safety level of levees in Spain depends mainly on their characteristics and how they have been built: design, materials, and execution of works. In that sense, levees protecting towns have seen a gradual improvement over time (both stability and permeability) through specific actions or coincident with repairs after a flood event. Levees protecting agricultural areas, as already mentioned, do not have a planned maintenance.

With the implementation of the Water Framework Directive and the Floods Directive, different studies are currently being developed, which will help to show the real situation of levees in Spain.

The implementation of the programme of measures of the Flood Risk Management Plans (Floods Directive) and the River Basin Management Plans (Water Framework Directive) are a good opportunity to identify all the existing levees; assess their functionality, status and environmental impact; and, with all this information, establish a policy allowing the optimization of all these aspects.

In recent years, works on the optimization of levees have started, taking into account the objectives of the Water Framework Directive, making space for the rivers and improving their functionality. For instance, in the Douro River District (www.chduero.es) more than 80 km of levees with poor functionality have been already removed.

10.5 Guidelines and good practices

Currently, we do not have Guidelines and Good Practice documents specifically for levees. They are planned to be developed during the implementation of the Flood Risk Management Plans.

As significant examples of good practices in optimizing existing levees, Spain has recently implemented two important river restoration projects:

- Órbigo River in Douro basin (http://www.chduero.es/VerVideo-previo-orb2.aspx)
- Arga River and Aragon River in Ebro basin (http://www.territoriovison.eu/)

10.6 Common practices during Levee Life Cycle

Generally, it is complex for the different authorities and stakeholders to be able to develop planned management in levee safety, because of the limited budget available. In recent years, there has been only budget for repairs after flooding events.

10.7 Critical knowledge and data gaps; critical research needs

The first knowledge gap is to have a real knowledge of the location and status of existing levees. It is necessary to carry out detailed inventories.

Then, it would be very interesting to have basic criteria for the design of the levees: location, materials and construction techniques, and basic aspects of maintenance as well as management of the residual risk arising from an eventual failure and its relationship with urban planning behind the levees. Another big challenge is the removal or relocation of existing levees with low functionality.

10.8 Summary of key facts

The current situation can be summarized in the following items:

- There are no official inventories of levees, dykes or embankments. A first estimate of their total length could be of several thousand kilometres.

- Levees have usually small heights (up to 3-5 metres), protecting agricultural areas and small villages for low return periods.

- In recent years there have been frequent failures after flooding events.

- Unlike dams and reservoirs, there is no specific legislation or technical guidelines on the design, maintenance and safety management of levees.

- Since 2008 a royal decree regulates where levees can be located, establishing a clear limitation to the construction of levees too close to rivers: "Except in exceptional cases, levees can only be built in the floodway for protecting existing populations".

- The implementation of the programme of measures of the Flood Risk Management Plans (Floods Directive) and the River Basin Management Plans (Water Framework Directive) are a good opportunity to identify all the existing levees; assess their functionality, status and environmental impact; and, with all this information, establish a policy allowing the optimization of all these aspects.

- This optimization, based also on green infrastructure and natural water retention measures, will produce an increase of the river areas and the improvement of their status, all within the framework of adaptation to climate change.

10.9 References

http://www.magrama.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/

11 Switzerland

As a landlocked country with a river network of approx. 65,500 km and 79 lakes with a surface > 0.5 km^2, flood protection and levees play a major role in Switzerland and characterize the appearance of all main watercourses. Due to the country's location in the western Alps, the majority of the Swiss population lives in river valleys and substantial parts of the Swiss economy are located in regions prone to flooding. In contrast to other European countries, flood events in Switzerland are often characterized by rather short durations, lasting from several hours to a few days. As a result, levees and other flood defences are only exposed to high water levels for short periods of time.

Until the mid-19th century Swiss valleys were dominated by unregulated streams with wide floodplains. To protect the population in endangered areas and for the creation of agricultural and residential areas, extensive river training projects were carried out on almost all major river streams from the 18th to the 20th century (see orange labels in Figure CH-1).

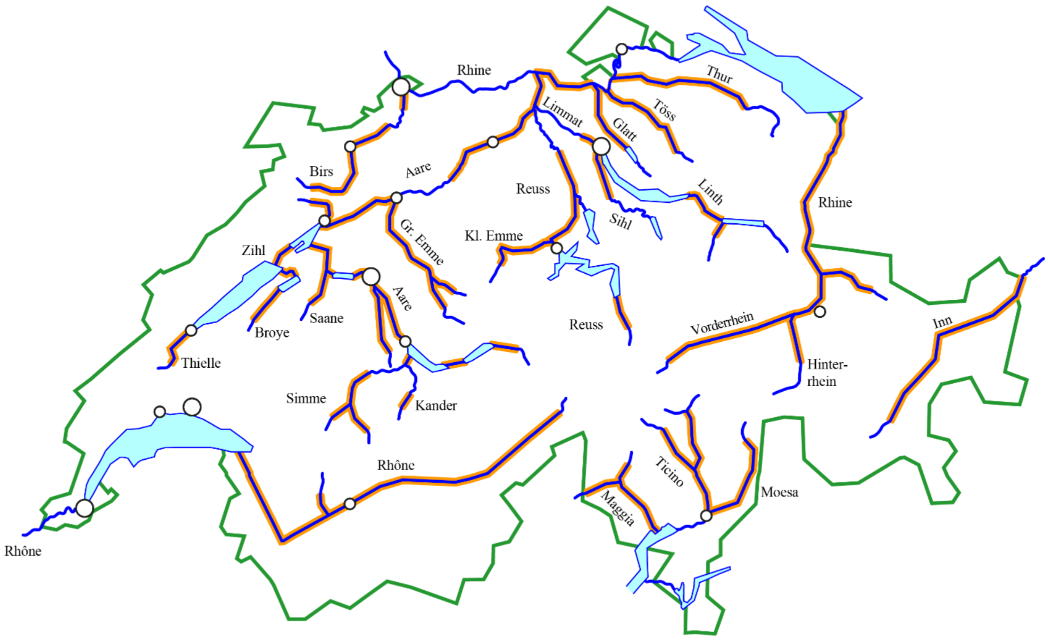

Figure CH-1: River training in Switzerland in the 18th and 19th century [XIX], extensive river training labelled in orange.

The corresponding flood protection levees, usually built with local material and without heavy machinery, still exist on many reaches. A proporion of those over 100-year old structures no longer meet modern technical design standards. Furthermore, the regulatory approach to flood protection and river engineering has changed fundamentally in Switzerland. As a result, large-scale renewal and river training operations have been constructed forstav the last 30 years and these will be continued in the next decades, for example at the River Rhone and the River Rhine.

11.1 Facts and figures on Swiss levees and flood defences

Switzerland does not have a central dam or levee register, as the responsibilities for hydraulic structures and flood protection are split between various federal, cantonal and local agencies (see chapter 1.4). The underlying data for this study was gathered via a questionnaire produced in close consultation with the Swiss Federal Office for the Environment (FOEN) and sent to all relevant federal states and other river authorities. Data gaps were closed by literature review and online research by the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of ETH Zurich.

The rivers studied were selected according to their national significance, e.g. rivers crossing cantonal borders or international watercourses, and their history in regard to past river training measures (see Figure CH-1). This study focuses on Swiss pre-alpine rivers, where levees and other flood defences are extensively used. Mountain torrents and smaller rivers were not taken into account. Figure CH-2 gives an overview of the rivers investigated in this study.

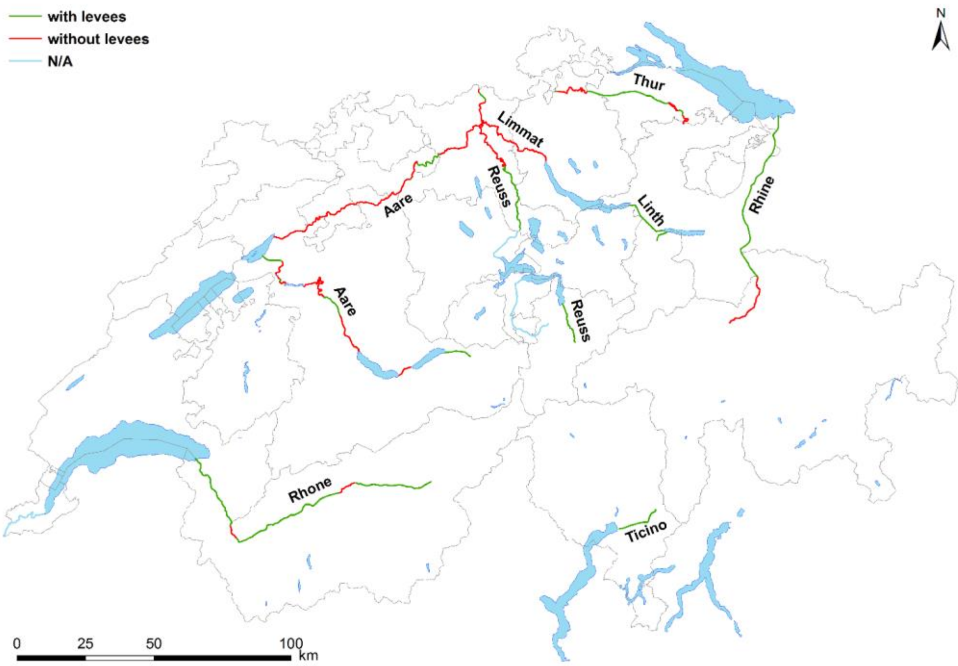

Figure CH-2: Reaches with/without levees on main Swiss pre-alpine rivers (source: VAW).

Based on a GIS analysis, Table CH-1 shows the respective river reach lengths according to the classification in Figure CH-2 and their share of the total river reach length. The levee position (one-bank or on both banks) was not considered for the calculation of the levee lengths.

Table CH-1: Distribution of levees on studied river reaches and classified percentages of total reach lengths

	lengths [km]			
river	length of river reach	with levees	without levees	no information available
Aare	211.8	46.5	165.3	-
Limmat	36.5	-	36.5	-
Linthkanal (*Linth*)	17.0	17.0		
Escherkanal (*Linth*)	5.4	5.4	-	-
Reuss	88.9	44.9	27.5	16.4
Rhine (*Alpenrhein*)	91.1	67.3	23.8	-
Rhone	144.0	105.7	13.0	25.3
Thur	67.7	35.3	32.5	-
Ticino	16.9	16.9	-	-
Total	679.4	339.0	298.6	41.7
% of total reach length		49.9	44.0	6.1

In the Swiss federal system, flood protection is under cantonal supervision (see chapter 1.4). Therefore, the legal responsibility for a river system can be split between several federal states (boundaries shown as grey lines in Figure CH-2). Table CH-2 shows the available information on levee lengths, the respective design floods and the levee structures per river section based on the questionnaire sent to the federal states (capitals in parentheses: abbreviations of Swiss federal states).

Table CH-2: Levee lengths, design floods (protection level) and levee structures per river section

river section	levee lengths [km]	design flood	levee structure
Aare (BE)	25.6 (incl. 2x8 from Hagneckkanal)	HQ100	earthfill dam, partly with drainage
Aare (SO)	5.2	HQ100	earthfill dam
	0.3	HQ100	dam with concrete-core
Hasliaare (BE)	2 x 10.9	HQ30 (left bank) / HQ100 (right bank)	earthfill dam without drainage
Linthkanal (*Linthwerk*)	2 x 11	HQ100 / PMF (without safety margin)	earthfill dam
Escherkanal (*Linthwerk*)	1 x 4	HQ100 / PMF (without safety margin)	earthfill dam
Reuss (AG)	33	HQ100	earthfill dam
Reuss (UR)	2 x 15.8	HQ100 / HQ150 (downstream of overflow section)	earthfill dam, surface seal on one short sector
Rhine (*Alpenrhein*, SG, GR)	2 x 40	HQ100	international section: dam with core
	2 x 26.3	HQ100	Swiss section: homogenous dam, built with local material
Rhone (VS)	2 x 144	HQ100 / PMF (on sections with high damage potential)	old sections: earthfill dams newer sections: zoned earth-fill
Thur (TG)	42.5	HQ100	earthfill dam with local surface seal
Thur (ZH)	1.2	HQ100	*N/A*
Ticino (TI)	23 (2 x 6.1+10.8)	HQ100	*N/A*
Total	**630.8**		

Typical levee heights in Switzerland range between 1 and 5 m, with typical slopes of about 1:3. If the levees are used as access roads for maintenance and inspection, the crest width is about 3 to 4 m, in other cases about 2 m.

Specific overflow sections in levees are increasingly used mitigation measures in Switzerland and are an integral part of many flood protection projects currently under development. In case of discharges exceeding the design flood, a certain percentage of the discharge is directed to areas with lower damage potential. As a result, the peak discharge might be reduced, but more importantly endangered areas downstream can be protected from levee failures. These overflow sections are designed as floodable or erodible dams or can be implemented via mechanical structures serving as sacrificial, relief structures. Table CH-3 gives a list of overflow sections in the studied rivers sections with levees (see Figure CH-2).

Table CH-3: Overflow sections in river sections with levees

river section	location	design flood	type of overflow section	source of information
Aare (BE)	Gürbemündung	HQ100	floodable	questionnaire
Aare (BE)	Hagneckkanal	HQ150-200	erodible	[03]
Hasliaare (BE)	Balm	N/A	floodable	[XVII]
Reuss (UR)	Erstfeld	HQ100	floodable	questionnaire
Reuss (UR)	Altdorf	HQ50	floodable	questionnaire
Reuss (UR)	Schattdorf	HQ150	floodable	questionnaire
Reuss (UR)	Seedorf	HQ20	floodable	questionnaire
Thur (TG)	Haslibecken	1.5xHQ100	floodable	questionnaire

Public awareness of the important role of levees has increased due to several extreme flood events in the last decades. With major flood protection projects ongoing on most of Switzerland's main rivers, the majority of the existing (partly over 100-year old) earthfill dams will be renewed or replaced over the next decades. The approach to flood protection projects and the overall strategy in river engineering have changed fundamentally in Switzerland since the first publication of the Federal Law on Flood Control in 1991 [014]. Recent flood protection projects are in most cases combined with river restoration measures, for instance local enlargements of the river bed. The Federal Act on the Protection of Water [018] puts a strong emphasis on the preservation and restoration of natural flow regimes, adequate sediment transport rates and defines the need of adequate space for watercourses.

In the international section of the River Rhine, a large-scale flood protection project currently under development illustrates the paradigm shift during the last decades [XII]. In the 19th century, the course of the River Rhine was straightened via two meander cut-offs with a uniform channel width of about 100 m. The first priority was to increase the slope of the river and to accelerate the discharge for increased sediment transportation and flood protection. Up to now, the structure of the riverbed consists of small inner dams that confine the river channel. In flood conditions, the floodplains (widths 75 – 100 m) are submerged and massive levees on both riversides protect the surrounding valley (see Figure CH-3).

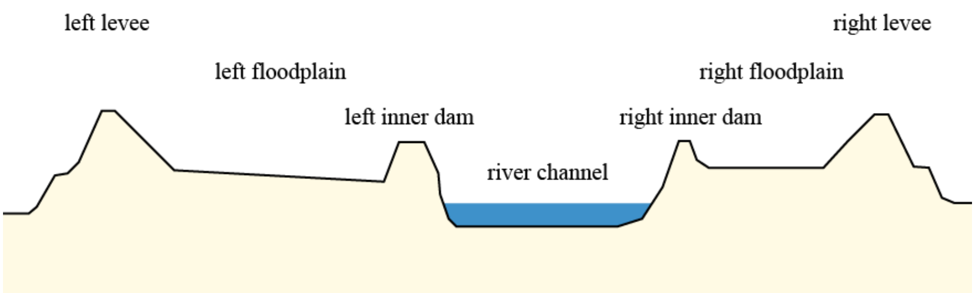

Figure CH-3: Exemplary cross section of the river Rhine since 19th century [025] (edited by VAW).

A modern flood protection project under development since 2005 combines an increase in flood protection with a significant ecological improvement. One of the main measures planned is the removal of the inner dams and the floodplains, creating a large riverbed that is adequate for flood run-off as well as sediment transport and provides sufficient space for the development of near-natural morphodynamic structures. (see Figure CH-4).

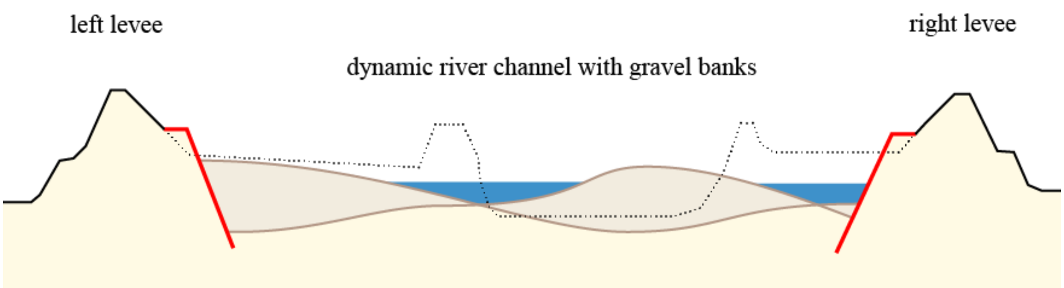

Figure CH-4: Exemplary cross section after realisation of the new flood control project [025] (edited by VAW).

11.2 Protected value, safety standards and flood risk

As built-up areas are expanding and subject to intensive use, the risks by natural hazards and the resulting damage potential in Switzerland are constantly increasing. According to a report on natural hazards in Switzerland published by the FOEN in 2016 [011], 1.8 million people live in flood-prone areas (based on a 1 in 500 year return period) (Figure CH-5). 1.7 million workplaces are located in those areas, as well as material assets worth 840 billion CHF.

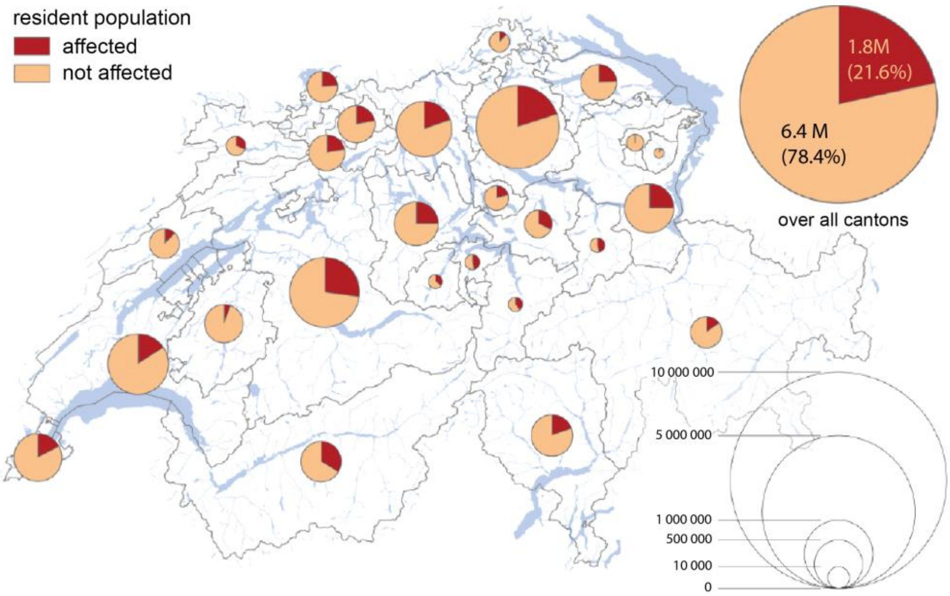

Figure CH-5: Proportion of population living in flood-prone areas regarding a flood event with a return-period of 500 years [011] (edited by VAW).

On behalf of the FOEN, a consortium of engineering companies and research facilities developed EconoMe, an assessment tool for analysing the balance between the costs and benefits of flood protection projects. Via this tool the effectiveness of those projects in risk reduction, including scenarios for levee breaches, and their economic benefits can be evaluated. Since 2008, the use of EconoMe is obligatory in projects that are financially supported by the FOEN.

The potential damage, and thus the value to be protected, of all river sections with levees in Switzerland can only be estimated via large-scale estimations. According to the questionnaires returned, the potential damage due to floods has not been identified by all cantons. Furthermore, the underlying criteria for the calculations of potential damage differ between federal states. Table CH-4 shows the available information on damage potential and the corresponding benefit-cost-ratio for the investigated river sections with levees.

Table CH-4: Damage potential and benefit-cost ratio of river sections with levees

river section	damage potential [CHF]	scenario	benefit-cost ratio [-]	source of information
Aare (BE)	material assets: 1.4 billion people(monetarized): 13.9 billion	HQ_{100}	1.2	EconoMe [III]
Aare (SO)	118 million	HQ_{100}	1.48	questionnaire / EconoMe
Hasliaare (BE)	50 – 60 million	HQ_{100}	-	questionnaire
Linthwerk (GL/SG/SZ)	280 – 300 million 350 million	HQ_{100} HQ_{300}	-	[022]
Reuss (AG)	244 million	HQ_{1000} with levee breach	-	[II]
Rhine (*Alpenrhein*)	2.5 billion		-	[024]
Rhone	8.3 - 10.3 billion		-	[021]
Thur (TG)	115 million 400 million	HQ_{100} PMF	1.57	questionnaire

Levees are typically designed with respect to specific design discharges, corresponding to certain hydrological return periods. The design flood HQ100 for instance corresponds to a discharge value which occurs statistically once every 100 years (probability of occurrence per year 1%). The return period is an appropriate indicator to compare the protection level of different river sections, as the discharge is compared to the size of the river and other influencing factors.

In Switzerland, protection levels are differentiated via a risk-based assessment of the target areas. , Following recommendations by the FOEN and the Federal Office for Spatial Development (ARE). matrices of protection goals that form the basis for all current flood protection projects have been developed by most cantons By this means, industrial areas as well as towns or villages with substantial damage risks receive a higher degree of protection than agricultural land or forested areas.

Figure CH-6 shows the ARE's recommendation for a protection goal matrix against natural hazards. The columns on the left show «object categories» sorted in ascending order according to their damage potential. The columns «protection goals» on the right represent return periods of the corresponding natural hazard event. The recommended level of protection is shown in shades of blue: light blue stands for complete protection, dark blue for a lack of protection. The numbers in the boxes indicate 'safety limits of intensity', which are for flood events determined by flow velocity (v) multiplied by water depth (h). According to Figure CH-6, dense settlements and industrial facilities have to be fully protected against flood events with a 100-year return period. Against this background, most levees in Switzerland have a 100-year design flood or higher. For specific levee sections in highly sensitive industrial areas or dense settlements, higher design floods are frequently applied (see Table CH-2).

Since the determination of design floods and the corresponding water levels are subject to hydrological uncertainties, the application of a freeboard as a safety factor is common use in Switzerland. To guarantee a specific discharge capacity, the freeboard denotes a vertical safety margin between the water level (calculated or observed) and the crest of the levee or other hydraulic structures . In addition to planning uncertainties, the freeboard compensates for external influences such as wave formation, backwater effects by obstructions or additional safety requirements underneath bridges.
Table CH-5 shows the freeboard values for the studied river sections with levees. Some cantons or decision makers apply constant values (e.g. 1 m), others use the velocity head of the design flood as reference. Although not legally binding, a unified concept for the determination of the required freeboard has been published in 2013 and is now applied in most flood protection projects in Switzerland [XVI].

Table CH-5: Freeboard values for studied river sections with levees.

river section	freeboard dimension	source of information
Aare (AG)	freeboard included in design flood water levels; under bridges and at flow velocities > 2 m/s = 0.2 m	[X]
Aare (BE)	energy head, min. value 0.5 m	[I]
Aare (SO)	0.8 m	[02]
Hasliaare (BE)	0.5 m	[XVII]
Limmat (AG)	0.5 - 0.8 m	[IV]
Limmat (ZH)	min. value 0.5 m	[01]
Linthkanal (*Linth*)	energy head 0.3-0.4 m + safety margin 0.3 m	[XIII]
Escherkanal (*Linth*)	energy head 0.7-1.0 m + safety margin 0.5 m	[XIII]
Reuss (AG)	0.5 m	[IX]
Reuss (UR)	0.5 m	[XV]
Rhine (*Alpenrhein*)	0.4 - 1.3 m	[XVIII]
Rhone	0.5 – 1 m	[013]
Thur (TG)	1.2 m	questionnaire
Thur (ZH)	min. value 0.5 m	[01]

Due to their permanent impoundment, levees influenced by backwater effects of water retaining facilities (e.g. hydroelectric plants) have different safety standards than flood protection levees (see Figure CH-12). The respective Swiss regulation on security for water-retaining structures [05] differs between «extraordinary» and «extreme» situations, in which the corresponding water stages are compared to specified risk values. Their exceedance would endanger the stability of the hydraulic facility in question and must be prevented in all circumstances. For «extraordinary» situations the design flood has a return period of 1000 years, in «extreme» situations return periods > 1000 years are required. Near to hydraulic facilities, within a project-specific perimeter defined by public authorities, no minimal freeboard needs to be included. The concessionaire must prove that the design flood can be diverted without harm to the hydraulic facility and that overtopping of the retaining structure can be prevented. Outside of this perimeter, the requirements for impoundment levees are quite similar to flood protection levees. The corresponding design flood has return periods between 100 and 300 years. In these cases, a safety freeboard of at least 0.5 m is required [05].

Object category				Protection goals			
				Return period [years]			
No	Property value	Infrastructure facility	Nature value	1–30 often	30–100 rare	100–300 very rare	>300 extremely rare
1		Mountain and ski tour routes (according to SAC map)	Natural landscape	3	3	3	3
2.1		Commercial hiking paths and skiing trails, corridors, conduits of local importance		2	3	3	3
2.2	Unoccupied buildings (sheds, pasture stables, etc.)	Transport routes of local importance, conduits of cantonal importance	Forest with protective function, land useful for farming	2	2	3	3
2.3	Parttime or permanently occupied individual buildings and hamlets, stalls	Transport routes of cantonal or major community importance, conduits of national importance, mountain railways, zones for downhill skiing, and training grounds	Forest with protective function if it protects dense settlements	1	1	2	3
3.1		Transport routes of national or major cantonal importance, skilifts, cablecars		0	1	2	3
3.2	Dense settlements, commerce and industry, building zones, camping sites, leisure and sport facilities	Stations for various transport uses		0	0	1	2
3.3	Special risks or special vulnerability or secondary damage	Special risks or special vulnerability or secondary damage		**Determination case by case**			

Key

- (lightest shade) = complete protection = no intensity permitted = 0
- (light shade) = protection from medium and strong intensities = weak intensity permitted = 1
- (medium shade) = protection from strong intensities = medium intensity permitted = 2
- (darkest shade) = lack of protection = strong intensity permitted = 3

Figure CH-6: Protection goal matrix recommended by the ARE [020] (edited by VAW).

11.3 Recent major floods and (near-)failures of levees

On behalf of the FOEN, damages caused by severe weather conditions have been monitored in Switzerland since 1972 and stored in a nationwide database [012]. The cumulative cost of damage since 1972 is around 13.7 billion CHF (adjusted for inflation), which leads to a mean damage of approximately 305 million CHF per year. This total amount incorporates not only damages by natural floods or debris flows, but also landslides and rockfalls. As shown in Figure CH-7, the biggest damages were caused by floods and debris flows and are dominated by a few major events.

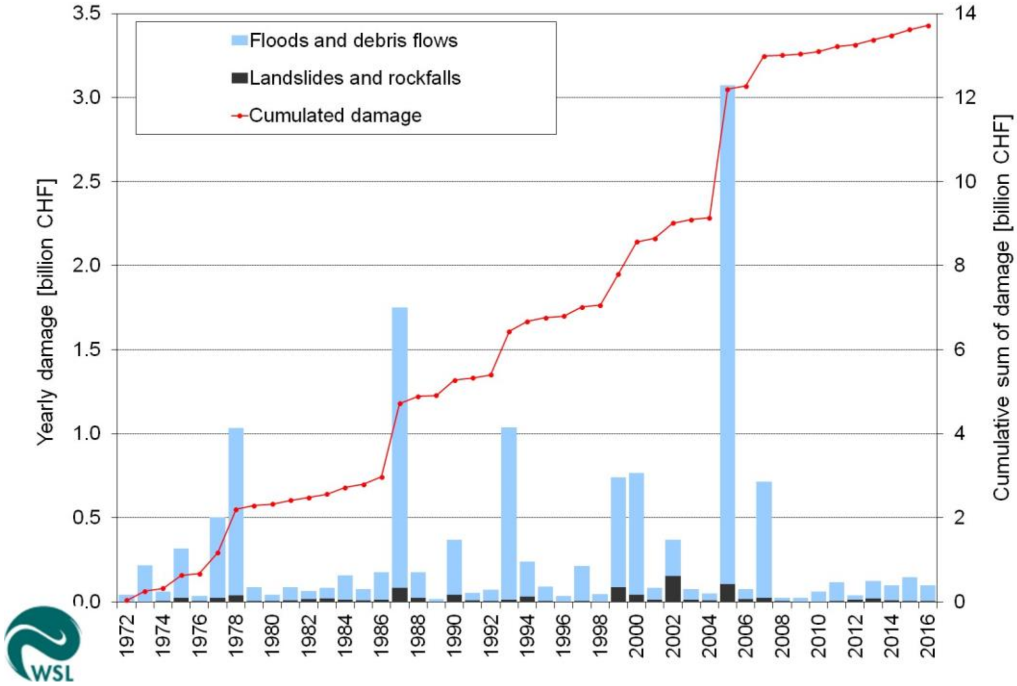

Figure CH-7: Damage costs per year 1972 – 2016; left axis (columns): annual damage costs; right axis (lines): cumulated damage costs [012].

In the past 30 years, 4 extreme flood events triggered nationwide investigations on their backgrounds and causes. These findings are still highly influential on future flood protection projects in Switzerland and are therefore summarisedbelow.

The flood of 1987 consisted of three independent events over the summer and occurred in different regions of Switzerland. Due to the combination of a cold winter with heavy snowfall and a very humid spring, the soil was mostly saturated at the beginning of summer. Subsequently, intensive and local rainfall events with recurrence periods of up to 500 years in combination with snow melting resulted in extensive floods across the country. These events caused eight deaths, the total damage over the year was estimated at 1.2 billion CHF [XI]. Table CH-6 gives an overview over the registered (near-) failures of levees during the flood events of 1987.

Table CH-6: Levee failures and near-failures during the flood event of 1987.

river section	dates	return period [years]	Description
	July 1987		strong effluent levee seepage at Kriessern (SG) on left river bank; heavy risk of levee failure due to piping
Rhine	July 1987	50	strong effluent levee seepage at St. Margrethen (SG) on left riverbank; heavy risk of levee failure due to piping
	July 1987		levee breach on the left side at Fussach due to overtopping
Reuss (UR)	24./25. August 1987	150 - 300	levee breach at several locations due to overtopping [XI]

The large impact of the flood of 1987 is exemplified by the events in the valley of the River Reuss in canton Uri. Due to a flood with a return period of 150 years, the existing 100-year old levees at the Reuss broke at three locations, which led to the inundation of 270 ha of agricultural land (Figure CH-8).

Figure CH-8: Flooding of the Reuss-valley in canton Uri in August 1987 [XI].

The winter of 1999 was characterized by heavy snowfall and therefore high water storage in the mountains. Two intense rainfall events (10-15 May and 22 May) during the thawing period and reduced retention capacitycaused by elevated water levels in the lakes led to high peak discharges. The total sum of direct damages was estimated at 580 million CHF. The major damages were caused by high water levels in several lakes, local failures of levees and overtopping of banks at the rivers Aare, Thur and Rhine [VII].

Table CH-7: Levee failures and near-failures at flood event of 1999.

river section	return period [years]	Description
Aare (BE)	>150	two breaches (length 10 m, depth 1 m) upstream Hunzikenbrücke; heavy damage to buildings and infrastructure, notably airport Belp
Linthkanal (GL/SG/SZ)	150	imminent hydraulic failure with inboard sliding of the levee due to internal erosion / piping; emergency measures prevented massive flooding of the Linth valley
Thur (TG)	50 - 200	breach of 25 m in length; damages to several buildings

The flood of October 2000 led not only to peak discharges in rivers or high water levels in lakes, but also to heavy material and personal damage due to landslides and rockfalls (see Figure CH-7). The total damage was estimated at approx. 670 million CHF, with 16 casualties. The flood of 2000 was a very important event for the canton Wallis: As shown in Table CH-8, the levees of the River Rhone broke at several locations (Figure CH-9 and Figure CH-10), leading to the inundation of up to 1027ha in the surrounding valley. At several locations along the course of the River Rhone, higher damage was only prevented by local emergency measures. In the aftermath of the flood event, the canton launched the third flood scheme for the River Rhone , which incorporates the entire length of the river and will be implemented in the next decades. The total investment is estimated at approx. 2 billion CHF, in contrast to a damage potential of approx. 10 billion CHF.

Table CH-8: Levee failures and near-failures at flood event of 2000 [VIII].

river section	return period [years]	description
Rhone (VS) Visp	110	water levels reached levee crests, levee failure was imminent; raise of levee crests with local emergency measures prevented higher damages and flooding of surrounding area
Rhone (VS) Varen	200 - 300	levee breach on a length of 100 m

Rhone (VS) Chamoson	<100	levee breach on a length of 100 m; high risk of explosion due to open gas pipeline; spillage of 3.5 million m^3, leading to the inundation of approx. 386 ha; evacuation of several thousand people

Figure CH-9 (left): Levee breach at the River Rhone near Chamoson in October 2000 [021].
Figure CH-10 (right): Water outflow after levee breach near Chamoson in October 2000 [021].

The flood of 2005 is especially remarkable because of its huge monetary damage. Given the total cost of approx. 3 billion CHF with six casualties, the event has generated higher damage than any other severe weather since records in Switzerland began in 1972. Most of the damage was caused by static and dynamic water processes (92% of total loss), while the impact of avalanches and mudflows was relatively small [V]. Approx. 900 towns and villages were affected, representing a third of all municipalities in Switzerland. As shown in Table CH-9, two major levee failures occurred during the event and led to severe damages in the surrounding area.

Table CH-9: Levee failures and near-failures at flood of 2005 [V].

river section	return period [years]	description
Hasliaare (BE), Meiringen	100-200	overtopping of levee at left riverside due to internal erosion on a length of 100 m, flooding of surrounding area; in total 4 levee breaches, total damage 28 million CHF
Reuss (UR), Amsteg	20-50	levee breach due to overtopping; flooding of highway and railway tracks; obstruction of swiss north-south-axis for several days

Figure CH-11: Levee breach at river Aare near Meiringen (BE), August 2005 (© Swiss Airforce).

11.4 Legislation and governance

11.4.1 Implementation of EU Regulations

As the Swiss Confederation is not a member of the European Union and neither flood protection objectives nor constructive guidelines are part of the bilateral treaties between the two parties [04], the EU legislation has no direct impact on the national legislation in Switzerland. Nevertheless, Switzerland has various international treaties concerning border rivers with its neighbouring countries [015], e.g. for the river training of the River Rhine with Austria (concluded in 1892 with former Austria-Hungary, renewed in 1924 and 1954).

11.4.2 National Legislation

The federal system being a cornerstone of the Swiss political system, the country is made up of 26 cantons (federal states), which are again divided in more than 2,300 municipalities. Legislative and executive power is shared between those three organisations, whereas only the confederation and the cantons have judicial powers. In contrast to many other countries, protection against natural hazards and thus flood protection are not part of national legislation in Switzerland, but under cantonal supervision. The federal government has national legislative authority in the flood control sector, yet each canton is responsible for related projects.

The Swiss Confederation, represented by the FOEN (Federal Office for the Environment) or the SFOE (Swiss Federal Office of Energy), defines the legal framework and provides support for flood protection projects in the form of financial assistance and consultancy services. By this means, the confederation is also responsible for the harmonisation of cantonal regulations and the supervision of national programmes.

Table CH-10: Main Swiss federal laws and ordinances concerning flood protection.

federal act / ordinance	abbreviation	civil code
Federal Law on Flood Control	WBG	SR 721.100
Ordinance on Flood Control	WBV	SR 721.100.1
Land-Use Planning Act	RPG	SR 700
Waters Protection Act	GSchG / WPA	SR 814.20
Fisheries Act	BGF	SR 923.0
Protection of Nature and Landscape Act	NHG	SR 451
Forest Act	WaG	SR 921.0
Environmental Protection Act	USG	SR 814.01
Federal Law on Hydropower Use	WRG	SR 721.80
Federal Law on Water Retaining Facilities	StAG / WRFA	SR 721.101
Federal Law on Agriculture	LwG	SR 910.1
Federal Law on Dispossession	EntG	SR 711
Federal Law on Financial Aid and Compensation	SuG	SR 616.1
Water Retaining Facilities Ordinance StAV SR 721.101.1	StAV	SR 721.101.1

Among others, the Federal Law on Flood Control and the respective ordinance (see Table CH-10) determine the conditions under which cantonal projects get financial support by the federal state. Federal contributions to flood protection projects can amount to half of the project’s total cost, depending on the potential damage, the protected value and the project’s quality. In emergency situations, e.g. after flood events, additional costs can be covered by federal authorities. To get federal subsidies, the respective project has to reflect the federal philosophy in flood control management and a cost-benefit analysis has to be carried out in the assessment tool «EconoMe» (see chapter 1.2). As a result, the applicants are required to apply the same methodology and planning processes can be harmonized across Switzerland.

Impoundment levees are seen as an integral part of the corresponding water retaining facility, which fall under federal law and are supervised by the SFOE. At transitions from flood protection levees (cantonal legislation) to impoundment levees (national legislation) and vice versa, the reach of the backwater level and thus the limit between federal and cantonal jurisdiction is dictated by the maximum operation level plus 1 m (see Figure CH-12). In individual cases, responsibilities on specific hydraulic facilities can be delegated from federal to cantonal jurisdiction.

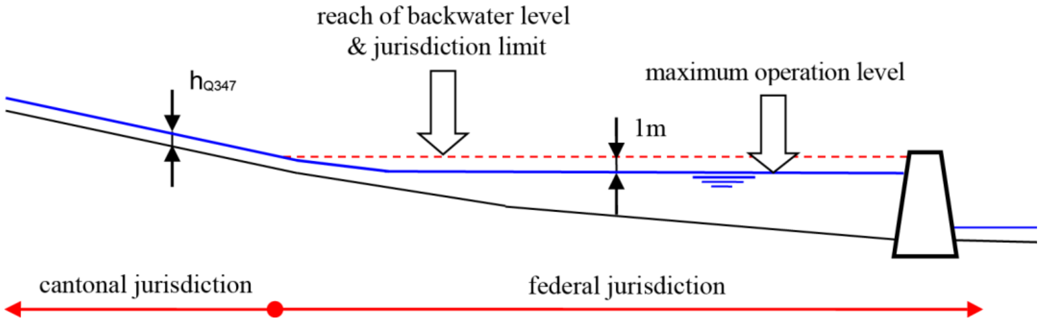

Figure CH-12: Jurisdiction limit at water retaining facilities [05] (edited by VAW).

The cantons carry out federal flood control laws and enact regulations necessary for their implementation. They are responsible for river channel maintenance, land-use planning as well as structural measures. Furthermore, they are also the authority for the compilation of hazard maps as well as emergency planning and emergency organization. As a result, most cantons have specific hydraulic engineering laws and respective ordinances, leading to a heterogeneous legal framework (see Table CH-10) .

A specific aspect of the cantonal autonomy on hydraulic engineering is the existence of agreements and treaties on flood control between cantons. This is often the case for rivers that cross cantonal borders or constitute the border between federal states, e.g. the River Rhine or the River Linth . These agreements involve definitions of the river's geographic properties and shared investments on flood protection, as well as regulations on supervision and maintenance of levees.

In the case of the River Rhine, the first agreements between riparian cantons date back more than 150 years. Subsequently, the cantons of St. Gallen (SG) and Grisons (GR) along with the Principality of Liechtenstein and the State of Vorarlberg in Austria formed a common platform, the Alpenrhein International Governmental Commission (Internationale Regierungskommission Alpenrhein, IRKA), in order to foster collaboration between all stakeholders by coordinating necessary interventions, improving information exchange and the equitable distribution of costs.

Concerning the River Linth, the three riparian cantons Glarus, St. Gallen and Schwyz and the canton of Zurich created with the Linthwerk (1823) and the Linthkommission (1862) similar panels, which are in charge of operation and maintenance of the channels of the Linth river itself and a system of surrounding canals.

11.4.3 Governance

Depending on the canton, the competence on flood protection is divided between the cantonal administration, the municipalities, other associations and corporations or the residents themselves. Watercourses exceeding a certain size ("rivers") are generally under direct responsibility of the respective cantonal authority for construction and environment. Municipalities are mainly responsible for maintenance and supervision as long as these measures don't exceed a certain extent. Every canton has a dedicated commission responsible for flood protection and river engineering.

11.5 Guidelines and good practices

The entities of the federal government, such as the FOEN or the SFOE, are responsible for the implementation of federal law and the promotion of federal policies in the cantons. Federal policies are promoted through consulting services and targeted subsidies. The FOEN regularly releases guidelines on flood protection and river restoration, including technical advice. As flood protection is cantonal legislation, the use of those guidelines by the responsible authorities is not mandatory, but strongly recommended if federal subsidies are required for the realization of a project. The main goal of these guidelines is to reduce the margin of interpretation of the federal legislation and to assure their correct implementation. Table CH-11 shows a list of the major guidelines on flood control, issued by the federal authorities.

Table CH-11: Guidelines on flood control in Switzerland by federal authorities.

guideline title	publisher	year of publication	reference
Hochwasserschutz an Fliessgewässern (published by the predecessor authority BWG)	FOEN	2001	[012]
Empfehlung Raumplanung und Naturgefahren	ARE	2005	[020]
Revitalisierung Fliessgewässer. Strategische Planung.	FOEN	2012	[XIV]
Guideline on Security of Water Retaining Facilities (Richtlinie über die Sicherheit der Stauanlagen)	SFOE	2014/2015	[05]
Programmvereinbarungen im Umweltbereich 2016 -2019	FOEN	2014	[VI]

The publications above primarily focus on legal issues, strategic planning or other issues on a larger scale, like project management or emergency planning. No specific guidelines on design and engineering aspects are available in Switzerland regarding the technical implementation of flood protection levees. Although not legally binding, the construction guideline SIA 267 of the Swiss society of Engineers and Architects (SIA) defines standards for dams made of loose material, regardless of their purpose. This document is one of the few references for the dimensioning of levees in Switzerland. Because the majority of levees also serve as roadbeds, another relevant entity is the Swiss Association of Road and Traffic Professionals (VSS), which publishes standards concerning roadbed construction and stability.

Many cantonal authorities comply with the rather general standards issued by SIA and VSS, and developed more specific standards for their jurisdiction (e.g. SG, BE) or use standards of neighbouring countries (e.g. Austrian standards for SG, German standards for SG and UR). In addition, the authorities refer to a pool of experts with a solid understanding,.therefore, the majority of expertise lies in the hands of Swiss hydraulic engineering companies.

11.6 Common practices during Levee Life Cycle

On the federal level, no regulations on monitoring or regular maintenance of flood protection levees exist, therefore, common practices during levee life cycles vary between cantons or even municipalities. Impoundment levees and the respective transverse hydraulic structures fall in most cases under the jurisdiction of the SFOE. The operators are obliged to establish regulations governing the surveillance of the facility and its auxiliary installations in normal operation and during extraordinary events. Continual inspections, annual inspections and five-yearly inspections are compulsory and the gathered data must be transmitted to the SFOE [016].

In most cantons, an annual inspection of the levees is common practice and mainly carried out by the responsible cantonal authority. Following the instructions of specific guidebooks, the annual results serve as basis for maintenance and restoration works. The exact procedure and extent of these inspections vary from canton to canton. Several river authorities, such as the Linthkommission (see chapter 1.4) seek additional advice from independent experts in river engineering, ecology and geotechnical engineering.

For every major river in Switzerland, the river bed levels are monitored on a regular basis (usually every 10 years) by federal authorities to quantify changes in the river bed (aggradation or erosion) and supervise sensitive river sections (e.g. bridges). In various cantons these investigations are accompanied by integral inspections of the levees. In most cantons, flood events of certain magnitudes trigger a subsequent inspection of the levees. These minimal return periods vary between 10 years (SG) and 50 years (BE).

Usually, an annual report is issued by the cantons containing the monitoring results of all relevant river sections. The required maintenance works are discussed within the cantonal authorities and subsequently completed either as part of the regular maintenance work or in the form of a specific project. The difference is of a financial and administrative nature: Specific projects are generally directly subordinated to the canton authority whereas regular maintenance work is carried out by the municipalities.

11.7 Critical knowledge and data gaps; critical research needs

Relevant authorities in Switzerland would be interested in monitoring possibilities for existing dam structures. Especially dams or levees in revitalized river sections must be monitored on a permanent basis and non-destructive methods for the assessment of their structural properties would be valuable. In general, practitioners and specialists on levee maintenance should be closely involved in any research activities to benefit from their experience and expertise.

11.8 Summary of key facts

- Facts and Figures 1: Switzerland has a long history in flood protection, as extensive river training projects have been carried out on all major river streams from 18th to 20th century. As a result, over 100-year old flood protection or impoundment levees still exist on many river sections. Large-scale river training operations are ongoing on many rivers and will be continue through the next decades. The majority of the existing earthfill levees will be renewed or replaced in coming decades.
- Facts and Figures 2: There is no central dam/levee register in Switzerland. All levees are situated along rivers. On a total length of studied river reaches of 679.4 km, 49.9% (339.0 km) were protected by levees. 44% (298.6 km) of the river reaches do not dispose of levees, for 6.1% (41.7 km) no information was available. Overflow sections to handle overload scenarios are increasingly used.
- Facts and Figures 3: Typical levee heights in Switzerland range between 1 and 5 m with slopes of about 1:3. If used as access roads for maintenance and inspection, the levee crest width is about 3 to 4 m, in other cases about 2 m.
- Protected value: 1.8 million people in Switzerland live in flood-prone areas (return period 500 years). 1.7 million workplaces and material assets of 840 billion CHF are located in those areas. The required protection levels are defined by protection goal matrices, allowing a risk-based assessment of target areas. Federal recommendations are put into action by the cantons.
- Recent (near-) failures: Since 1972, the cumulated damage by natural hazards amounts to around 13.7 billion CHF, leading to a mean damage of around 305 million CHF per year. In the past 30 years, 4 large flood events (1987, 1999, 2000, 2005) led in total to 4 major near-failures and to at least 12 major levee failures.
- Governance & legislation: EU legislation has no impact on flood protection in Switzerland, except on boundary rivers. Flood protection is under cantonal legislation, the federal authorities define the legal framework and provides financial and technical support. Impoundment levees are in most cases under federal legislation.

- Guidelines & good practice: Guidelines on flood protection and river restoration are released by federal authorities, their usage is not mandatory to cantons. No specific guidelines on design and engineering of flood protection levees are available in Switzerland, but those of neighbouring countries are frequently used.
- Common practices: There are no regulations on monitoring or maintenance of levees on federal level. Annual inspections are common practice. During and after major flood events (return period > 10 years), additional monitoring or maintenance measures are implemented.

11.9 References

List of abbreviations

AG	Canton of Aargau
ARE	Federal Office for Spatial Development
BE	Canton of Berne
EU	European Union
FOEN	Federal Office for the Environment
FOWG	Federal Office for Water and Geology
GIS	Geographical information system
GL	Canton of Glarus
GR	Canton of Grisons
IRKA	International Governmental Commission of the Alpine Rhine
LU	Canton of Lucerne
SFOE	Swiss Federal Office of Energy
SG	Canton of St. Gallen
SIA	Swiss Society of Engineers and Architects
SO	Canton of Solothurn
StAV	Ordnance on Water Retaining-Facilities
SZ	Canton of Schwyz
TG	Canton of Thur
UR	Canton of Uri
VS	Canton of Valais
VSS	Swiss Association of Road and Transport Professionals
ZG	Canton of Zug
ZH	Canton of Zurich

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12 United States of America

12.1 Facts and figures on levees and flood defences

In the United States (U.S.), there are two main types of infrastructure that are relied upon to reduce the risk of flooding:

- Levees: A levee is a manmade barrier that does not cross a watercourse (i.e. river) and has a primary purpose to reduce the risk of flooding due to high water, storm surges, precipitation, and other weather events.
- Dams: A dam is a manmade barrier that does cross a watercourse (i.e. river) and has purpose to store, control, or divert water.

Levees are defined as systems (referred to as "levee systems") that consist of earthen embankments, floodwalls, and other features which act collectively to reduce the risk of flooding to a portion of a flood plain (referred to as "leveed area"). Typically, levee systems are subjected to short duration flood loadings ranging from a few days to a few months. In general, levee systems are defined as having a height greater than 3 feet, a leveed area greater than 1,000 acres, or a population in the leveed area of at least 50 individuals (WRRDA 2014).

Levee system features may consist of embankment sections, floodwall sections, closure structures, pumping stations, canals, and interior drainage works. These features may serve purposes beyond flood risk reduction including transportation related purposes such as highway or railroad embankments or recreational related purposes such as pedestrian or bike trails.

Dams are often comprised of embankments and appurtenant features such as hydraulic spillways, gates, and conduits necessary to store, control, or divert water. Dams are commonly relied upon to reduce the risk of flooding in the watercourse downstream of the barrier. Typically, dams often have a permanent storage of water behind them but can also have a temporary storage of water if their purpose is to provide water detention during certain weather events. In general, dams are defined as having a height 25 feet or greater or water storage capacity of 50 acre-feet or more (FEMA 2004).

Due to their existence along (i.e. levees) and across (i.e. dams) watercourses, dams and levees often interact in many ways. Water releases from dams are either controlled (through gated hydraulic structures) or uncontrolled (through ungated overflow spillways) and can cause flood loadings on levees along downstream channels and rivers.

Nationwide databases documenting the location and condition of levees and dams are maintained by the U.S. Army Corps of Engineers (USACE). The location and condition of dams in the U.S. can be found in the National Inventory of Dams (NID) at http://nid.usace.army.mil/. The U.S. has over 90,000 dams identified in the NID (ASDSO 2018). Roughly eighty percent (80%) of the dams in the NID are regulated by states within the U.S. through State Dam Safety Programs. State Dam Safety Programs help to ensure the safety of dams in the U.S. by conducting inspection of existing dams, providing remediation oversight of deficient dams, and coordinating the work of local officials and dam owners on emergency preparedness. Since this report is primarily focused on levee systems in the U.S., the reader is referred to the National Dam Safety Program website (https://www.fema.gov/dam-safety) and U.S. engineering and technical societies such as American State Dam Safety Officials (ASDSO, http://www.damsafety.org/) and United States Society on Dams (USSD, http://www.ussdams.org/) for information on dams in the U.S..

The location and condition of levees in the U.S. can be found in the National Levee Database (NLD) at http://nld.usace.army.mil/. In 2007, U.S. congressional legislation through the Water Resources Development Act (WRDA) authorized the establishment of the NLD to include an inventory of all federal levees in the U.S. (WRDA 2007). In 2014, U.S. congressional legislation through the Water Resources and Reform Development Act (WRRDA) further required the NLD to include an inventory of levees provided by states, the Indian tribes, and other entities responsible for the regulation and oversight levees (WRRDA 2014). The NLD includes information on the location, condition, and structures and population behind levee systems in the U.S..

Currently, the NLD has over 8,700 levee systems totaling almost 30,000 miles in length. These levees shown in Figure US-1 include levees within USACE authorities[6] (2,200 levee systems totaling 14,150 miles in length), and levees outside of USACE authorities (6,600 levee systems totaling 14,600 miles in length), primarily collected by FEMA's National Flood Insurance Program and levee information provided voluntarily by federal agencies, states, and levee owners. The National Committee on Levee Safety (NCLS 2009) estimates there are over 100,000 miles of levees in the U.S., which suggests that the locations of over 70% of the levees in the U.S. are unknown. USACE directly operates and maintains about 190 levee systems totaling 4,200 miles in length within its authorities. Other remaining levees within USACE authorities are managed by a combination of states and levee districts in conjunction with USACE. Across the nation, there is a lot of variation in the non-Federal entities responsible for the operation and maintenance of levees, ranging from state agencies to local volunteer levee districts to everything in between. Some of these entities have taxing authorities and others do not which result in budget limitations.

USACE has collected levee information regarding condition and flood risk for those levees within its authorities. This information allows for analysis to better understand levee characteristics (i.e. type, height, features, etc.), people and infrastructure behind levees (i.e. population at risk, value of property behind levees, etc.), and key factors that influence flood risk posed by levees (i.e. levee performance, flood hazards, consequences associated with poor levee performance, etc.). Analysis of this information is provided in this section and in the following section. This analysis provides insight to the benefits and challenges associated with levees in the U.S., but only represents a portion of the levees in the U.S. Similar levee information and analysis for those levees outside of the USACE authorities is not available and unknown.

For levees within USACE authorities, earthen embankment represent 97% and floodwalls represent 3% of the 14,150 miles of levees. Consistent with Figure US-1, most levees systems are located along rivers and other waterways. Coastal levee systems only represent roughly 5% of the levees within USACE authorities. The average age of levees within USACE authorities is roughly 50 years or older, as of 2018. Historically, engineering practices for levee design and construction have widely varied across the U.S. and many levees have a long and complex construction history that span several decades and original construction often predate modern day engineering practices. USACE has constructed over 12,000 miles of levee, with each levee reflecting the engineering standards and location conditions during its design and construction. Earthen embankment levees were typically constructed of locally available materials from relatively shallow borrow pits or dredging operations in adjacent rivers or streams. Thus, earthen embankment levees can consist of a wide range of soils including fine-grained soils (clays and/or silts), coarse grained soils (sands and/or gravels), and rock fill.

Levee heights vary considerably in the U.S based on local flood loading conditions and levee system flood performance requirements. For levees within USACE authorities, the average levee height is approximately 14 feet, the maximum levee height is over 40 feet, and the minimum levee height is less than 3 feet. Across the U.S., typical levee embankment sections varies regionally as shown in Figure US-2. USACE division boundaries (shown in Figure US-1) represent regional boundaries and for the most part follow watershed boundaries. Mississippi Valley Division contain over 6,200 miles of levees and generally have taller and wider levees than the average levee section in the U.S. Northwestern Division contain over 2,400 miles of levees and South Pacific Division contains over 2,300 miles of levees. Both divisions generally have shorter and narrower levees than average levee in the U.S..

[6] Levees within USACE authorities includes: (1) levees that are operated and maintained by USACE, (2) levees that are USACE constructed but are locally operated and maintained by a non-federal sponsor, or (3) levees that are locally operated and maintained by a non-federal sponsor and active in the USACE federal program under Public Law 84-99 (Flood Control and Coastal Emergency Act).

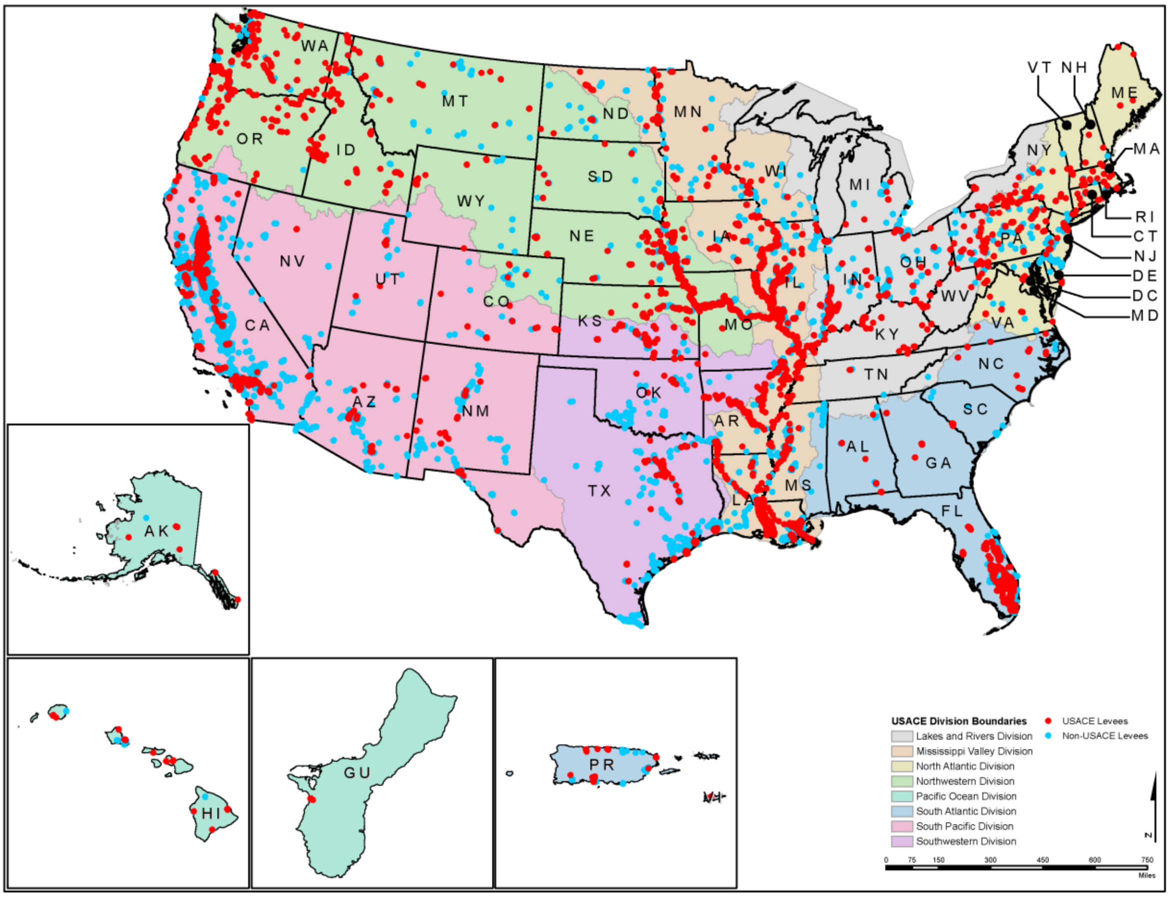

Figure US-1. Map showing the levees in the U.S. by state/territory including those levees within USACE authorities (Red color - USACE Portfolio Levees) and those levees outside of USACE authorities (Blue color - Outside USACE Portfolio Levees). [Source – National Levee Database 2018].

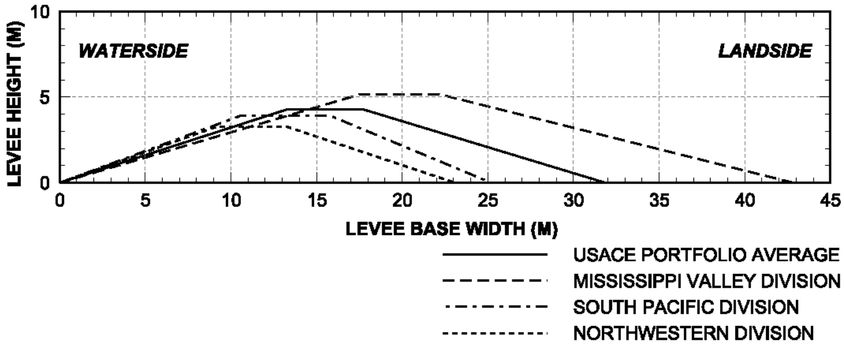

Figure US-2. Graph showing the average levee section in the U.S, average levee section in Mississippi Valley Division, average levee section in Northwestern Division, and average levee section in South Pacific Division.

Across the 2,200 levee systems within USACE authorities, the following are general statistics of levee system features:

- 16,000 culverts exists through or beneath levees. Culverts are features in levee systems commonly used for management of interior drainage. Improper construction or deterioration can lead to seepage related failure modes for a levee system. Majority of these culverts are less than 48 inches in diameter. The two most common culverts found are corrugated metal pipes and concrete pipes. Culverts constructed from corrugated metal pipes, approximately 40% of the culverts in the portfolio, are no longer considered good practice for levee construction due to the likelihood of pipe corrosion and difficulties to achieving adequate compaction around the pipe leading to seepage related failure modes. Culverts often have closure features that prevent flood water from entering the leveed area. The most common closure feature on culverts are flap gates and sluice gates.

- Roughly half of all USACE levee systems have closure structures. Closures structures are commonly used to provide temporary closure of an opening in the levee system. Often these openings in the levee system are due to roadway, railway, or pedestrian walkway crossings. Common types of closures structures include sand bag type, stop log type, removable panel, and gate closure structures (i.e. swing gates, mitre gates, rolling gates, etc). Closure structures can range from less than 3 feet. (common for sand bag closures) to greater than 16 feet in height (common for structural closures).
- 2,500 pump stations exists within USACE levee systems. Pump stations are used to manage interior drainage behind levee systems to prevent flooding. Pump stations represent a significant operation and maintenance responsibility for levee owners. This responsibility includes staff to operate and maintain the pump station, maintenance of pumps, pipes, valves, and pump structure, and power requirements (main and backup) to operate the pumps during flood events.
- 10,000 relief wells exists along USACE levee systems. Relief wells are relied upon to reduce seepage pressures within and beneath levee systems. Relief wells are often installed along the land side toe of levees and are designed to safely collect and discharge seepage caused by flood loadings. Relief wells require periodic maintenance (i.e. every 5 to 10 years) to ensure the wells are functioning properly. An improper functioning well can lead to increased seepage pressures within and beneath levees and may result in seepage or stability related failure mode.
- 150 miles of I-walls exists within levee systems. I-walls are types of floodwalls that are commonly cantilever steel sheet pile embedded below the ground surface. I-walls heights can range from less than 3 feet and up to 20 feet in height but the average I-wall height is 6 ft. I-walls performed poorly during Hurricane Katrina in 2005, which resulted in five significant levee breaches within the New Orleans Hurricane Storm Damage Reduction System. I-walls under flood loadings are prone to develop a flood side gap adjacent to the wall, which if unaccounted for can cause the wall to be become unstable. I-walls are also vulnerable to overtopping erosion, which can lead to instability of the I-wall. Since Hurricane Katrina, new design and construction guidance has been issued to address these vulnerabilities.

12.2 Protected value, safety standards and flood risk

Assessing, managing, and communicating levee-related flood risk to people, property, and the environment is the mission of the USACE Levee Safety Program. Effectively managing risk is a shared responsibility between USACE, local non-federal entities that operate and maintain the levee, and local communities that live behind the levee. Shared responsibility includes prioritizing actions to manage and reduce levee risk, continually monitoring levee risk, and continually promoting awareness of levee risk to those are behind them. Managing the portfolio of levees requires an understanding of the levee-related flood risk within the portfolio. Utilizing the best available information on the USACE levee portfolio, including information gathered from inspections and risk assessments, a Levee Portfolio Report (USACE 2018) was created to share the current understanding of the flood risks and benefits associated with the portfolio of systems within the USACE Levee Safety Program. This report provides valuable information that allow for improved decision making and management of the portfolio.

Risk assessments within the Levee Safety Program provide a systematic, evidence-based approach for estimating and describing the likelihood and consequences of existing and future risk associated with levee systems. Risk assessments consider the potential flood hazards to a levee system, how the levee performs when faced with flood hazards, and the consequences (measured in population and property value) within the leveed area. A risk characterization is assigned for each levee system and is used to prioritize resources across the portfolio and to organize widespread levee-related risk information into reasonable commensurate groupings for future action. USACE has completed risk characterizations to nearly 73% of the portfolio. For the remaining 27%, USACE expects to complete levee risk characterizations within the next few years. Thus far, 13% of the portfolio consist of levee systems that are Very High, High, or Moderate risk that require interim actions to reduce risk while more long-term and comprehensive risk reduction and risk management solutions are being pursued. These systems have over 8 million people that live and/or work behind them. USACE has begun sharing information from risk assessments with levee sponsors and other community risk managers. USACE will continue to develop approaches and tools to share results with all kinds of risk managers, with a particular focus on training its staff to translate complicated risk information into understandable and actionable information.

USACE considers the full range of flood hazards for a levee, from when water first starts loading the levee to when water starts to flow over the top of a levee. The likelihood of when water starts flowing over the top of a levee varies considerable across the USACE levee portfolio. Within the portfolio, the annual chance of exceedance (ACE) of the flood loading that reaches the top of the levee ranges from 50% to less than 0.02%. The majority of the levee systems within the portfolio begin to overtop at flood levels with an ACE of 0.5% or less. USACE is continuing to invest in collection and assessment of flood hazards and is sharing information with other federal agencies to improve the understanding of hydrologic events.

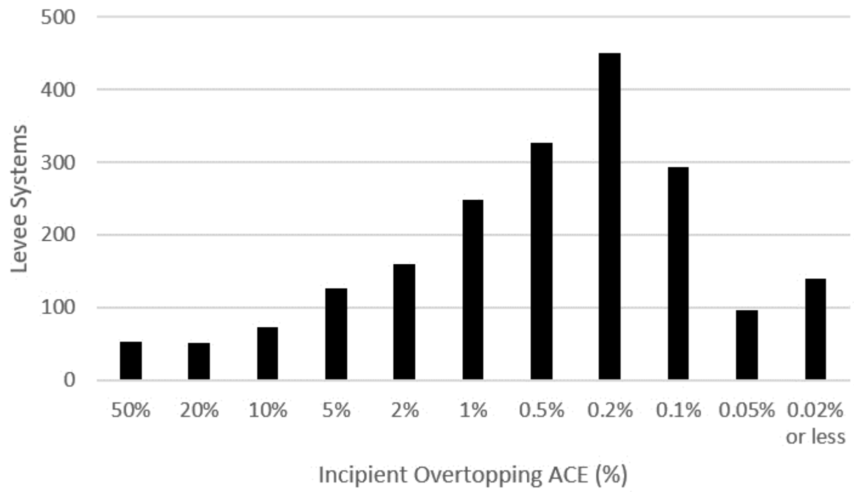

Figure US-3. Graph showing the distribution of levee systems within USACE authorities for incipient overtopping ACE from less than 100 yr. to 5,000 yr. The majority of levee systems have an ACE between 1% and 0.1%. (USACE 2018)

How the levee performs when faced with flood hazards is a factor in levee-related flood risk. Levees in the USACE portfolio vary widely in age, design, and construction practices, and flood regimes (e.g. coastal vs. river, flash vs. long duration). Risk drivers in levee performance can result from many different mechanisms that can cause the levee to breach. The most common risk driver in levee performance is when the levee is overtopped and breaches. This risk driver impacts over 40% of the USACE levee portfolio. Seepage through or beneath the levee is the second most common risk driver, impacting 17% of the portfolio. Understanding the uncertainty in how a levee will perform during flood events is important in managing risk. Monitoring performance, regular inspections, risk assessments, and continuous operation and maintenance are essential for the effective management of risk associated with levees.

Approximately 11 million people live and/or work and $1.3 trillion of property value exists in the levee area (e.g the area that represents the portion of the floodplain where floodwaters are excluded by a levee) of the USACE levee portfolio. The total leveed area in the portfolio is approximately 122,00 square miles, roughly the area of the country of Poland. Population and property value behind levees are not equally distributed; over nine million people (85% of the population behind the USACE levee portfolio) are concentrated behind roughly 150 levees (7% of the USACE portfolio). These 150 levees are in urban areas. While there are very large urban areas behind some levees, most of the levees (1,465 systems) in the USACE portfolio have relatively low populations (fewer than 1,000 people) working and living behind them. In addition to property, population, and economic activity, USACE portfolio levees reduce the risk of flooding to some of our most vital infrastructure. From roads and schools, to police and fire stations, to historical sites and national treasures, there are countless structures that provide invaluable services to our communities and nation that are located behind levees. For example, there are almost 4,500 schools located behind levees that collectively enroll over two million students and over 25% of the U.S. oil refining capacity is located behind levees. Damages to, or failure of, these levees could significantly impact local, regional, and national resources.

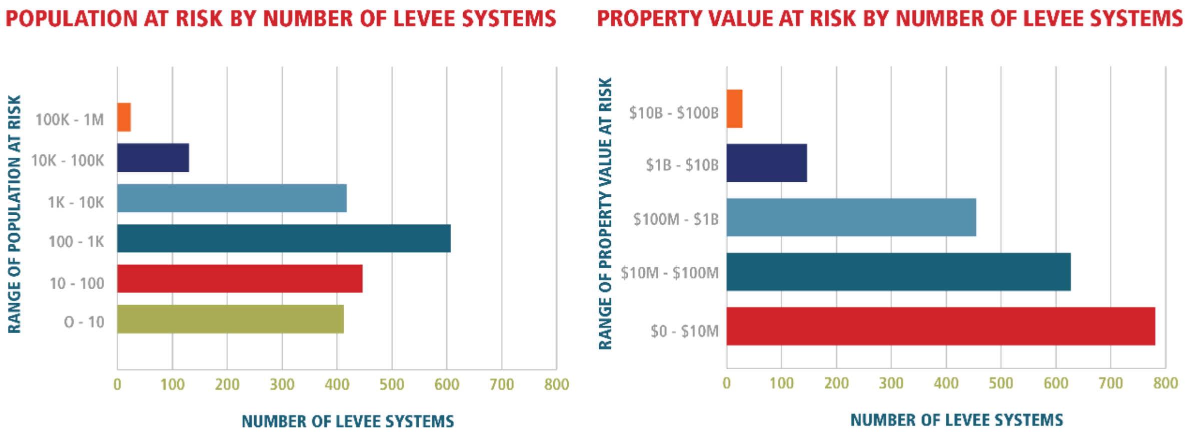

Figure US-4. Charts showing the distribution of total population and property value behind levees within USACE authorities. (From USACE 2018).

Flood awareness and emergency preparedness for individuals and communities behind levees play a significant role in managing risk posed by levees in the U.S. Involved, informed individuals and communities behind levees will be better prepared to take necessary risk reduction measures, such as purchasing flood insurance, making structural changes to business and residences to reduce exposure to flooding, providing adequate revenue (i.e. through taxes) for proper levee operations and maintenance, and taking proper measures to evacuate when required. These measures increase public safety and reduce the potential for property losses. Based on information collected by USACE on levees within its authorities, almost 200 levee systems have communities behind them that are generally unaware of the risk posed by the levee, due to a breach or overtopping event. These levee systems account for roughly 30% of the entire population behind levees within USACE authorities. Additionally, over 500 levee systems do not have evacuation plans for the population behind them and over 200 levee systems are unlikely to warn the population in an event of a levee breach, due to non-existent or outdated flood warning procedures. USACE will continue to support and apply the results of research and knowledge in social science to better understand how flood warnings are issued and how they spread through communities that experience severe flooding.

The cost to address risk in the USACE levee portfolio ranges from $6.5 billion to $38 billion, with an expected cost of about $21 billion. The expected cost of $21 billion is broken down into approximately $13 billion for levee infrastructure improvements to mitigate risk drivers in levee performance before the levee overtops, $8 billion in armoring of levees to mitigate risk drivers in levee performance when the levee overtops, and about $300 million to improve evacuation effectiveness within the leveed area.

The U.S. knows little about the condition or risks associated with levees outside those inspected and assessed as a part of the USACE levee portfolio. USACE continues to promote awareness of the location of levees and the risks associated with them. USACE is coordinating with states, tribes, local communities, and private levee owner/operators to conduct a one-time inspection and risk assessment for all levees in the U.S. USACE will collect information on the location, condition, risks, and benefits of these levees and include it within the National Levee Database to increase accessibility of levee information to those living and working behind levees, and to improve understanding of the U.S. benefits and risks associated with levees.

USACE prepares an annual report that documents flood damages prevented by flood risk reduction projects constructed by USACE (USACE 2018). Figure US-4 shows flood damages prevented (in $ billions) for USACE flood risk management projects since 2008. USACE flood risk management projects include infrastructure such as levees, dams, and channels. In 2011, the U.S. experienced an historical flood event along the Mississippi River valley in which over $260 billion was in flood damages were prevented by USACE flood risk management projects (i.e. levees, dams, and channels). In 2016 and 2017, the U.S. experienced more historical flooding in which over $190 and $249 billion in flood damages were prevented, respectively. The benefits and expenditures of USACE flood risk management projects since 1928 are shown in Figure US-5. Accumulated U.S expenditures currently exceed more than $150 billion while the accumulative benefits exceed $1,200 billion. USACE flood risk management projects provide $9.96 in benefits to the U.S. for every $1.00 invested.

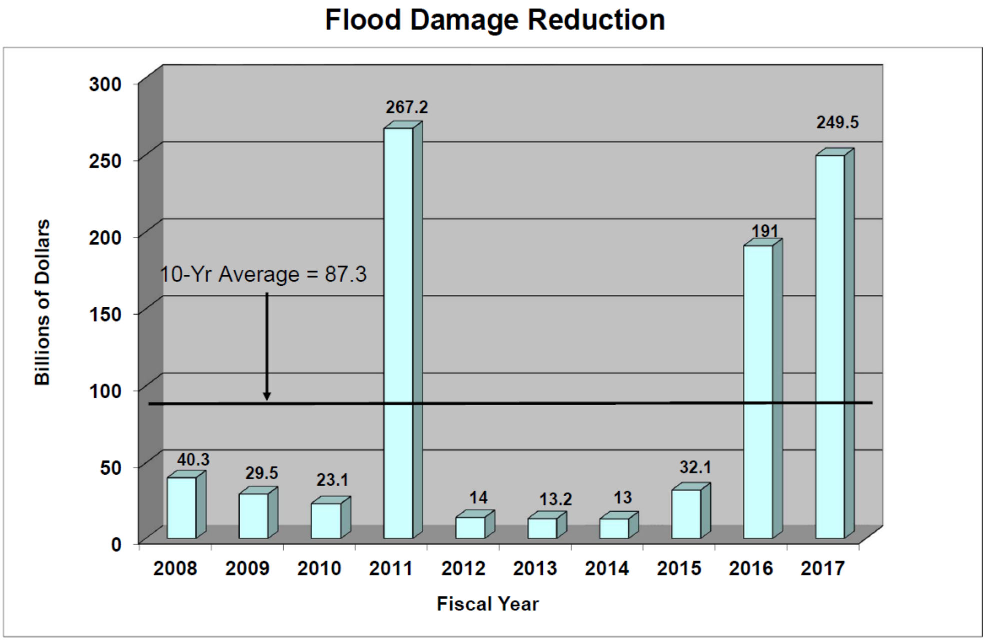

Figure US-5. Chart showing flood damages prevented (in $ billions) for USACE flood risk management projects since 2008. In 2011, 2016, and 2017, the U.S. experienced historical flood events in which over $260 billion, $190 billion, and $249 billion in flood damages were prevented by USACE flood risk management projects (i.e. levees, dams, and channels). (From USACE 2018)

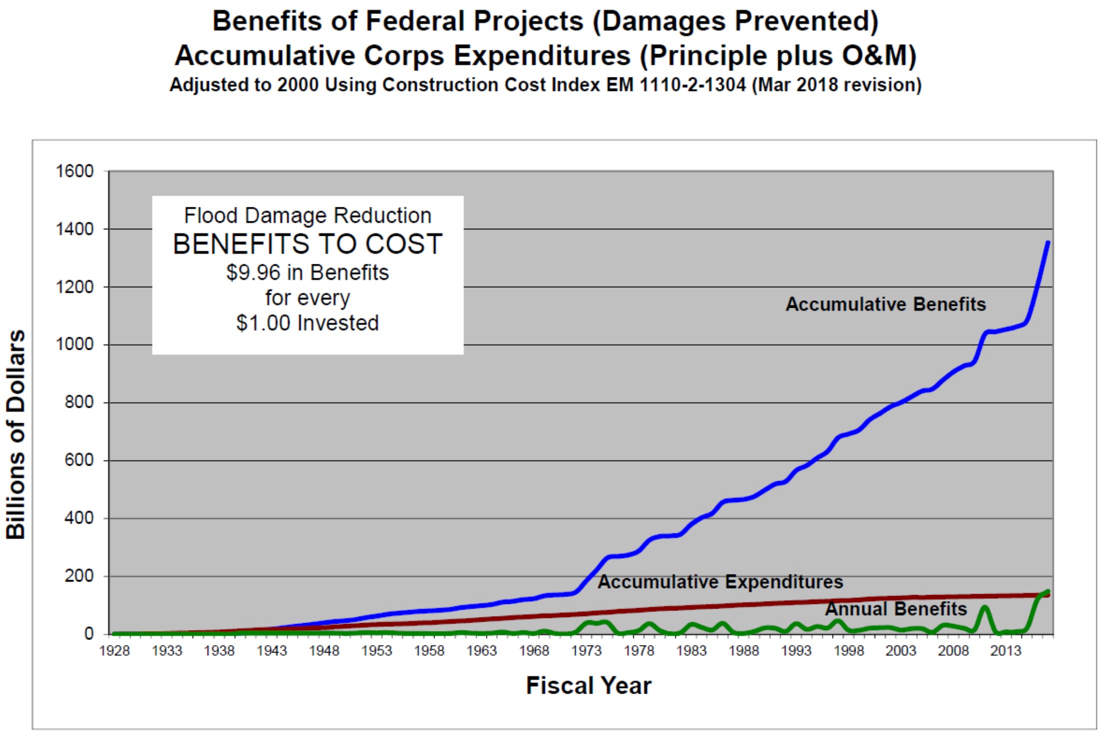

Figure US-6. Chart showing benefits and expenditures of USACE flood risk management projects since 1927. Accumulated U.S expenditures currently exceed more than $150 billion while the accumulative benefits exceed $1,200 billion. USACE flood risk management projects provide $9.96 in benefits to the U.S. for every $1.00 invested. (From USACE 2018)

Federal Emergency Management Agency (FEMA) and Levees

FEMA administers the National Flood Insurance Program (NFIP). This program consists of several components but the three basic ones are the flood mapping program; floodplain management, and flood insurance.

FEMA, through its mapping program, identifies and maps Special Flood Hazard Areas (SFHAs), i.e. areas subject to the 1%-annual-chance flood, on Flood Insurance Rate Maps (FIRMs). FIRMs are used to find out if a property is in the SFHA or other NFIP risk premium zones and determine the appropriate rate; and to enforce floodplain management requirements as required by law.

The 1%-annual-chance flood is a regulatory standard for the NFIP. The U.S. Department of Housing and Urban Development (HUD), which administered the NFIP before FEMA, initiated this program by calling on a group of experts to define the best standard to be used for insurance rating and floodplain management. The experts recommended that the 1%-annual-chance flood be used on the basis that it provides a higher level of protection while not imposing overly stringent requirements. The 1%-annual-chance flood was never intended to be a safety standard; but, it soon became a target design level for many communities as it allowed unrestricted development to continue and provided relief from mandatory flood insurance purchase for homeowners behind accredited levees but ironically resulted in increased risk in leveed areas.

It is important to note that it is not flood risk that is mapped on FIRMs but merely flood hazard associated with the 1%-annual-chance flood, because the analysis does not include consequence assessments. The 0.2%-annual-chance flood (500-year flood) is also mapped in some communities. There are no mandatory flood insurance requirements for structures located between the 1%- and 0.2%-annual-chance floodplains; however, communities could use this information to limit construction of critical or vulnerable facilities such as schools or hospitals in these areas.

Flood insurance risk premium zones fall in following categories:

- SFHAs (A, A1-A30, AE, AO, AH, A99, AR, V, V1-V30, V0, VE),
- areas of moderate flood hazard (shaded X, B)
- areas of minimal hazards (un-shaded X, C)
- areas of undetermined but possible flood hazard (D)

There are other symbols such as M, N, and P that can be used for areas of special, moderate and undetermined mudslide hazards and E that can be used for areas of special flood-related erosion hazard. Purchasing flood insurance and enforcing floodplain management are not required in areas of moderate or minimal flood hazards and in areas of undetermined but possible flood hazards; but are required for structures in SFHA's throughout the life of their mortgage. The dynamic nature of flooding can move areas in and out of SFHAs every time maps are updated.
FEMA does not own, operate, design or maintain levee systems. FEMA's NFIP regulations cover merely the requirements levee systems must meet to be recognized on NFIP maps as designed to provide protection against the 1% annual chance flood, which is referred to as accreditation. Once a levee system is accredited, the area between the levee and the 1%-annual-chance floodplain boundary on the landside is designated as shaded zone X. Shaded zone X represents moderate flood hazard therefore neither flood insurance nor floodplain management requirements are mandatory. Once an accredited system does not continue to meet the regulatory requirements, the system will be de-accredited and the area behind it will be mapped as SFHA.
NFIP's Community Rating System (CRS) recognizes and encourages community floodplain management activities that exceed the minimum NFIP standards. Depending upon the level of participation, flood insurance premium rates for policyholders can be reduced up to 45%. Communities impacted by levee decertification can turn to the CRS program to soften the insurance impacts of levee de-accreditation and reduce their flood risk at the same time. Flood insurance premium rates are discounted in increments of 5% as shown in the table below:

Table US-1 Insurance rates

CRS Class	Credit Points (cT)	Premium Reduction	
		In SFHA	Outside SFHA
1	4,500+	45%	10%
2	4,000–4,499	40%	10%
3	3,500–3,999	35%	10%
4	3,000–3,499	30%	10%
5	2,500–2,999	25%	10%
6	2,000–2,499	20%	10%
7	1,500–1,999	15%	5%
8	1,000–1,499	10%	5%
9	500–999	5%	5%
10	0–499	0	0

Communities participating in the CRS can obtain a maximum of 235 points for the following levee related risk reduction activities:

- Levee maintenance up to 95 points
- Levee failure threat recognition system up to 30 points
- Levee failure warning up to 50 points
- Levee failure response operations up to 30 points
- Levee failure critical facilities planning up to 30 points

As of May 2016, there are 1,391 CRS communities, spread across the entire nation. These communities represent a significant portion of the Nation's flood risk as evidenced by the fact that more than 68%

of all flood insurance policies are in CRS communities. Nonetheless very few communities have received credits for the abovementioned activities, so far.
Hazard mitigation in the NFIP is the effort to reduce loss of life and property by lessening the impact of disasters. It is most effective when implemented under a comprehensive, long-term mitigation plan. State, tribal, and local governments engage in hazard mitigation planning to identify risks and vulnerabilities associated with natural disasters, and develop long-term strategies for protecting people and property from future hazard events. Mitigation plans are key to breaking the cycle of disaster damage, reconstruction, and repeated damage. A FEMA-approved hazard mitigation plan is a condition for receiving certain types of non-emergency disaster assistance, including funding for mitigation projects. Ultimately, hazard mitigation planning enables action to reduce loss of life and property, lessening the impact of disasters. The Levee Safety Initiative authorized under the Water Resources Reform and Development Act of 2014 (WRRDA 2014) emphasized the importance of local and state hazard mitigation plans in leveed areas and made them a prerequisite for FEMA grants as well as USACE's rehabilitation funds.

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12.3 Recent major floods and (near-) failures of levees

Table US-2 Major flood events in the US

Year	Event	Location	Details
1862	California's Great Flood	Western U.S. (CA)	Beginning on December 24, 1861, and lasting for 45 days, the largest flood in California's recorded history occurred. The entire Sacramento and San Joaquin valleys in California were inundated for an extent of 300 miles (480 km), averaging 20 miles (32 km) in breadth. California state government was forced to relocate from the capital in Sacramento for 18 months in San Francisco. The rain created an inland sea in Orange County, lasting about three weeks with water standing 4 feet (1.2 m) deep up to 4 miles (6 km) from the river. The Los Angeles basin was flooded from the San Gabriel Mountains to the Palos Verdes Peninsula, at variable depths, excluding the higher lands which became islands until the waters receded. The Los Angeles basin lost

			200,000 cattle by way of drowning, as well as homes, ranches, farm crops & vineyards being swept-away. (Null et al. 2007)
1874	Mississippi River Flooding	Lower Mississip pi River (AR, MS, LA)	Major flooding on the Lower Mississippi resulted in congressional funding for USACE to study flood control. USACE concluded that most ongoing flood control efforts were uncoordinated and inadequate. (NCLS 2009).
1927	Great Mississippi Flood of 1927	Lower Mississip pi River (MO, IL, KS, TN, KY, AR, LA, MS, OK, TX)	One of the most destructive river flood in U.S. history. Flooding overtopped the levees, causing Mounds Landing to break with more than double the water volume of Niagara Falls. The Mississippi River broke out of its levee system in 145 places and flooded 27,000 square miles (70,000 km2). This water flooded an area 50 mi (80 km) wide and more than 100 mi (160 km) long. The area was inundated up to a depth of 30 ft. (9 m). The flood caused over US$350 million in damages and killed 246 people in seven states. (RMS 2007).
1986	California and Western Nevada Floods	Western U.S. (CA, NV)	On February 11, 1986 a vigorous low pressure system drifted east out of the Pacific, creating a “Pineapple Express” that lasted through February 24 unleashing unprecedented amounts of rain on northern California and western Nevada. The nine-day storm over California constituted half of the average annual rainfall for the year. Record flooding occurred in three streams that drain to the southern part of the San Francisco Bay area. Extensive flooding occurred in the Napa and Russian rivers. Napa, north of San Francisco, recorded their worst flood to this time while nearby Calistoga recorded 29 inches (740 mm) of rain in 10 days, creating a once-in-a-thousand-year rainfall event. Records for 24-hour rain events were reported in the Central Valley and in the Sierra. One thousand-year rainfalls were recorded in the Sierras. The heaviest 24-hour rainfall ever recorded in the Central Valley at 17.60 inches (447 mm) occurred on February 17 at Four Trees in the Feather River basin. In Sacramento, nearly 10 inches (250 mm) of rain fell in an 11-day period. System breaks in the Sacramento River basin included disastrous levee breaks in the Olivehurst and Linda area on the Feather River. Linda, about 40 miles (64 km) north of Sacramento, was devastated after the levee broke on the Yuba River's south fork, forcing thousands of residents to evacuate. In the San Joaquin River basin and the Delta, levee breaks along the Mokelumne River caused flooding in the community of Thornton and the inundation of four Delta islands. Lake Tahoe rose 6 inches (150 mm) as a result of high inflow. The California flood resulted in 13 deaths, 50,000 people evacuated and over $400 million in property damage. 3000 residents of Linda joined in a class action lawsuit Paterno v. State of California, which eventually reached the California Supreme Court in 2004. The California high court affirmed the District Court of Appeal's decision that said California was liable for millions of dollars in damages. (California Court of Appeal 2003).
1993	Midwest Flood of 1993	Central U.S. (MO, IL, MN, IA, KY)	Flooding resulted in 50 fatalities, $15.6 billion in damages, breaching or overtopping of 40 of 229 federal levees, and breaching or overtopping of 1,043 of 1,347 non-federal levees. (National Research Council 2012).
1997	Northern California Flood of 1997	Western U.S. (CA)	Flooding in the Sacramento and San Joaquin river basins forced 120,000 people to evacuate and caused about $2 billion in damages, including over $1 billion in damages of public infrastructure. (National Research Council 2012).
2005	Hurricane Katrina	South eastern U.S. (TX, LA, MS, AL, FL)	Hurricane Katrina was one of the deadliest and costliest hurricanes in U.S. history. Forming over the Bahamas, Katrina crossed Florida as a Category 1 storm and strengthened in the Gulf of Mexico. It made landfall in Southeastern Louisiana on August 29, 2005, impacting Louisiana as well as Mississippi, Alabama, Georgia, and the Florida panhandle to various degrees. The

			hurricane's storm surge that pushed ashore from the Gulf of Mexico was over 29 feet, the highest ever recorded in the United States. In total, over 1,700 people were killed and hundreds of thousands were displaced. The levee system protecting New Orleans, Louisiana, primarily built by USACE and operated and maintained by the local levee districts, failed in the aftermath of Katrina, and a significant portion of the city and surrounding areas were flooded. The National Flood Insurance Program (NFIP) experienced an unprecedented number of claims, 212,235, in the 2005 calendar year and over $17 billion dollars in loss dollars paid. The levee failure prompted litigation, congressional investigation, and a variety of investigations regarding the levee failure. The impacts of Katrina have been long-lasting economically, environmentally, and from the perspective of human and societal welfare of the city and surrounding area. Levee-related policy was reformed; for example, the National Levee Safety Program Act (2007), which directs USACE to carry out activities to enhance the safety of U.S. levees, was amended, and the USACE Levee Design Manual (USACE, 2000) was revised to incorporate risk-based concepts into levee design. (National Research Council 2013).
2008	Midwest Flood of 2008	Central U.S. (MO, IL, MN, IA, KY)	Flooding resulted in 11 fatalities and an estimated $2 billion in property loss; about $2.7 billion in federal disaster relief was approved in 2009 (National Research Council 2012).
2011	Mississippi River Flood of 2011	Mississippi River Valley (IL, MO, IA, TN, AR, LA, MS)	Floods caused no direct fatalities or breaches in federal levees. USACE induced breaching to activate floodways to reduce pressure on mainline river levees below St. Louis. (National Research Council 2012).
2012	Hurricane Sandy	Eastern U.S. (NY, RI, ME, NJ)	In the United States, Hurricane Sandy affected 24 states, including the entire eastern seaboard from Florida to Maine and west across the Appalachian Mountains to Michigan and Wisconsin, with particularly severe damage in New Jersey and New York. Its storm surge hit New York City on October 29, flooding streets, tunnels and subway lines and cutting power in and around the city. Damage in the United States amounted to $71.4 billion (2013 USD). (NOAA 2014).
2015	Mississippi River Valley Winter Flood of 2015	Central U.S. (IL and MO)	River levels in Illinois and Missouri had dramatically increased after a 3 day period of heavy rain that began around 24 December 2015. Some areas reported to have seen over 9 inches of rain fall during that time. By 31 December, the Meramec River near St Louis had reached record levels. The next day the Mississippi River had reached record levels at Thebes and Cape Girardeau. River and flash flooding over this time period caused over 20 deaths in Illinois and Missouri. In Missouri, that over 7,000 structures were damaged in the floods that hit the St. Louis area in late December 2015. (http://floodlist.com/america/usa/rivers-flood-arkansas-mississippi-and-tennessee-federal-emergency-missouri retrieved September 19, 2016)
2015	Texas and Oklahoma Floods of 2015	Southwestern U.S. (TX and OK)	Severe weather and record floods hit Texas and Oklahoma in May 2015, which was recorded as the wettest month ever in both states as the states received over 20 inches of rainfall in the month. Between May 26th and May 30th, 2015, 28 people were killed in Texas and 4 in Oklahoma due to severe weather and flooding. During the event, more than 5,000 homes sustained flood inundation in Texas, including in the metro regions of Houston, Austin and Dallas. Hundreds of additional homes sustained flood damage in the Oklahoma metro areas of Tulsa and Oklahoma City. (http://floodlist.com/insurance/texas-oklahoma-floods-cost-3-billion retrieved September 19, 2016)

2016	Louisiana Floods of 2016	South-eastern U.S. (LA)	A slow moving low pressures system dumped high levels of rain (over 17 inches of rain in a 24 hour period) and caused flash flooding in southeastern Louisiana between August 12-13, 2016. Thirteen fatalities were reported combined in the parishes of East Baton Rouge, Tangipahoa, Saint Helena, Livingston, and Rapides. A report from the Baton Rouge Area Chamber indicates more than 145,000 residences-housing upwards of 359,000 people-were in flood-affected areas; almost 12,000 businesses-which together employ more than 136,000 people-are in areas identified as flood-affected. The U.S. government declared 20 parishes as major disaster areas. FEMA issued USD 1 billion in Federal Disaster Assistance grants to those affected, including National Flood Insurance Program (NFIP) policy holders who have received more than USD 247 million to repair or rebuild damaged properties; more than 63,000 families have sought FEMA assistance for housing. The majority of homeowners impacted by the floods reportedly did not have flood insurance because their homes were not in flood zones, thus the financial burden of recovery is inhibiting progress. (http://floodlist.com/america/usa/air-estimates-insured-losses-louisiana-floods retrieved September 19, 2016)
2016 Oct.	Florida, Georgia, Carolinas	South-eastern U.S. (FL, SC, NC, GA)	Hurricane Matthew, 11 Dead, Inundation in 4 States after torrential rain and storm surges, as well as high winds. Matthew was the most powerful storm to make US landfall in more than a decade. The storm made landfall near McClellanville, South Carolina, as a Category 1 storm with sustained winds of 120 km/h. However, on Friday 07 October, the edges of Hurricane Matthew drenched Florida with heavy rain and flooded coastal areas with high waves and storm surge. The surge reached 12.5 feet at Tybee Island, Georgia. Severe flooding was reported in Savannah, Georgia after almost 1 foot (30 cm) of rain fell over 2 days, breaking previous records. Hunter Army Airfield in Savannah recorded 17.49 inches (444.25 mm). — MDA Weather Services, October 8, 2016. At around 10:45 on Saturday, 08 October, the storm made landfall in the Cape Romain National Wildlife Refuge near McClellanville, South Carolina, a small town about 35 miles (55 km) up the coast from Charleston, where severe flooding was also reported. The National Hurricane Center (NHC) said: "The combination of a dangerous storm surge, the tide, and large and destructive waves will cause normally dry areas near the coast to be flooded by rising waters moving inland from the shoreline." Record-breaking flooding occurred in North Carolina. Flood and flash flood warnings had been issued, including Raleigh, Durham, Fayetteville, Hope Mills, Chapel Hill, Carrboro, Sanford and Laurinburg. Fayetteville recorded 355 mm of rain in 24 hours. Many rivers and creeks were flooded, some major and a few at or above record levels. NWS Raleigh, October 8, 2016
2017	California	Western U.S. (CA)	Heavy, persistent rainfall across northern and central California created substantial property and infrastructure damage due to flooding, landslides, and erosion. Notable impacts include severe damage to the Oroville Dam spillway, which caused a multi-day evacuation of 188,000 residents downstream. Excessive rainfall also caused flood damage in the city of San Jose, as Coyote Creek overflowed its banks and inundated neighborhoods, forcing 14,000 residents to evacuate.(https://www.ncdc.noaa.gov/billions/events/US/1980-2018)
2017	Missouri, Arkansas, Illinois	Central U.S. (MO, AK, IL)	A period of heavy rainfall up to 15 inches over a multi-state region in the Midwest caused historic levels of flooding along many rivers. The flooding was most severe in Missouri, Arkansas, and southern Illinois where levees were breached and towns were flooded. There was widespread damage to homes, businesses, infrastructure, and agriculture. Severe storms also caused additional impacts during flooding events across a number of central and southern states. (https://www.ncdc.noaa.gov/billions/events/US/1980-2018)

2017	Texas	Southea-stern U.S. (TX)	Category 4 hurricane made landfall near Rockport, Texas causing widespread damage. Harvey's devastation was most pronounced due to the large region of extreme rainfall producing historic flooding across Houston and surrounding areas. More than 30 inches of rainfall fell on 6.9 million people, while 1.25 million experienced over 45 inches and 11,000 had over 50 inches, based on 7-day rainfall totals ending August 31. This historic U.S. rainfall caused massive flooding that displaced over 30,000 people and damaged or destroyed over 200,000 homes and businesses. (https://www.ncdc.noaa.gov/billions/events/US/1980-2018)
2017	Florida, South Carolina, U.S. Virgin Islands	Southea-stern U.S (FL, SC, USVI)	Category 4 hurricane made landfall at Cudjoe Key, Florida after devastating the U.S. Virgin Islands - St John and St Thomas - as a category 5 storm. The Florida Keys were heavily impacted, as 25% of buildings were destroyed while 65% were significantly damaged. Severe wind and storm surge damage also occurred along the coasts of Florida and South Carolina. Jacksonville, FL and Charleston, SC received near-historic levels of storm surge causing significant coastal flooding. Irma maintained a maximum sustained wind of 185 mph for 37 hours, the longest in the satellite era. Irma also was a category 5 storm for longer than all other Atlantic hurricanes except Ivan in 2004. (https://www.ncdc.noaa.gov/billions/events/US/1980-2018)
2017	Puerto Rico, U.S. Virgin Islands	Southea-stern U.S. (PR, USVI)	Category 4 hurricane made landfall in southeast Puerto Rico after striking the U.S. Virgin Island of St. Croix. Maria's high winds caused widespread devastation to Puerto Rico's transportation, agriculture, communication and energy infrastructure. Extreme rainfall up to 37 inches caused widespread flooding and mudslides across the island. The interruption to commerce and standard living conditions will be sustained for a long period, as much of Puerto Rico's infrastructure is rebuilt. Maria tied Hurricane Wilma (2005) for the most rapid intensification, strengthening from tropical depression to a category 5 storm in 54 hours. Maria's landfall at Category 4 strength gives the U.S. a record three Category 4+ landfalls this year (Maria, Harvey, and Irma). (https://www.ncdc.noaa.gov/billions/events/US/1980-2018)

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12.4 Legislation and Governance

The history of levees in the United States predates even colonization by Europeans. Early Native Americans constructed raised earthen structures along the Ohio and Mississippi Rivers as safe havens from flooding. Over time, techniques became more sophisticated, but the general policy of elevating above the flood was still considered effective.

The earliest recorded case law and federal legislative efforts that occurred to combat flooding and control riverine systems came in the mid-1800s. In 1824, in Gibbons v. Ogden, the U.S. Supreme Court interpreted the Constitution’s commerce clause (Article I, Section 8) to permit the federal government to finance and construct river improvements. Within two months, Congress appropriated funds and authorized the U.S. Army Corps of Engineers (USACE) to remove certain navigation obstructions from the Ohio and Mississippi Rivers. Then in 1849-50, the Swamp Land Acts transferred most of the swamp and overflow land from federal control to state governments along the lower Mississippi River on the condition that the states use revenue from the land sales to build levees and drainage channels. The Acts required no federal funds.

Over the course of the next 50 to 75 years, several devastating floods on major rivers across the U.S. sparked attention at the federal level. In 1917, a Flood Control Act (PL 64-367) was approved. Congress appropriated $45 million for a long-range and comprehensive program of flood control for the lower Mississippi and Sacramento Rivers. In doing so, Congress accepted federal responsibility for flood control. The Act included a requirement for local financial contributions in flood-control legislation and authorizes the USACE to undertake examinations and surveys for flood-control improvements and to provide information regarding the relation of flood control to navigation, waterpower, and other uses. Important precedents and frameworks were established for later flood control legislation.

Further devastation and significant loss of life caused by the great floods on the Mississippi and Ohio Rivers during the late 1920s and 1930s spurred new Congressional response, ultimately resulting in the Flood Control Acts of 1928 and 1936. These Acts established federal participation in the design and construction of flood control structures, including levees and dams. The USACE administered this program at full federal expense. What followed this landmark legislation was the design and construction of thousands of miles of levee systems, many providing protection from the “Standard Project Flood”— the largest reasonable flood that could be expected in the basin. Although these levees did not have a level of flood frequency assigned to them, many provided protection from unusual to extreme flooding in the range of 0.2-percent annual chance (500-year flood) to 0.1-percent-annual chance (1,000- year flood).

This trend in levee construction continued for almost four decades until new national policies began unintentionally encouraging the construction of less protective levee systems in some areas.

In 1968, the National Flood Insurance Act (Title XII of the Housing and Urban Development Act of 1968 [PL 90-448]) created the National Flood Insurance Program (NFIP) and the Federal Insurance Administration (FIA) within the Department of Housing and Urban Development (HUD) to provide flood insurance in communities that voluntarily adopt and enforce floodplain management ordinances that meet minimum NFIP requirements. One of the primary purposes of the NFIP was to address the inability of the public to secure privately backed insurance for economic losses from flooding,

Administered by the Federal Emergency Management Agency (FEMA), the NFIP designated the 1%-annual-chance event (100-year flood) as a special flood hazard area in which those holding federally related mortgages would be required to purchase flood insurance. Never intended to be a safety standard, the 1%-annual-chance event soon became a target design level for many communities as it allowed unrestricted development to continue and provided relief from mandatory flood insurance purchase for homeowners behind levees accredited to meet the 1%-annual-chance event within a relatively economical initial construction cost.

Title 44, Chapter 1, Section 65.10 of the Code of Federal Regulations (44 CFR 65.10) [https://www.gpo.gov/fdsys/granule/CFR-2011-title44-vol1/CFR-2011-title44-vol1-sec65-10] describes minimum design, operation, and maintenance requirements that must be met in order for levee systems to be accredited as providing a specific level of protection, determining insurance requirements for property owners. Guidance documents related to levee accreditation, mapping, and other related topics are available from FEMA [http://www.fema.gov/media-library/assets/documents/34953].

Meanwhile, an interesting parallel was occurring with regard to dams in the United States resulting in a National Dam Safety Program. The destruction and, more significantly, the loss of life as a result of the catastrophic failures of Teton Dam (Idaho, 1976), Kelly Barnes Dam (Georgia, 1977), and other dams resulted in legislation and executive orders for a new national policy initiating—the National Dam Safety Program, administered and led by FEMA. This program encouraged and incentivized the states to enact state regulations over dams and to improve their regulatory programs. Today, 49 of 50 states have dam safety laws and programs that provide for public safety through review, regulation, and standards for dams.

Unfortunately, there was no correlation between dams and the similar potential that existed for levees. The 1986 Water Resources Development Act (Public Law No. 92-662) provided new requirements for local cost sharing of flood control projects constructed by USACE. The 1986 law also required that lands, easements, rights of way and real estate be provided by local sponsors and an agreement was included requiring local sponsors to provide for all operations, maintenance, repair, rehabilitation, and replacement of flood control works.

These additional financial burdens on local communities made affordability of new levees and repairs of existing levees an emerging issue and began an unintended shift away from watershed development to individual projects. Affordability concerns, combined with minimum accreditation requirements, resulted in many levee systems being constructed to provide protection to only the 1%-annual-chance event—a de facto, unintentional, and dangerous adoption of an actuarial standard as a safety standard.

Riverine flooding on the Mississippi River in 1993 and in California in 1986 and 1987 spurred additional federal interest in flooding and the role of levees in flood damage reduction and floodplain management when substantial economic damage resulted. Even so, greater catastrophe was only narrowly avoided as most major levee systems protecting heavily urbanized areas held and there was little loss of life. Similarly, several hurricanes along the Florida peninsula (Andrew in 1992, Opal in 1995, Charley, Ivan, Frances, and Jeanne in 2004, and Dennis and Wilma in 2005) and eastern seaboard (Hugo, 1989) resulted in substantial flooding and economic damage but little loss of life.

A number of comprehensive and significant reports followed these events. For example, the Interagency Floodplain Management Review Committee, given the responsibility for conducting a comprehensive review of floodplain management after the 1993 Midwest floods, published Sharing the Challenge: Floodplain Management Into the 21st Century (sometimes referred to as the "Galloway Report," after the committee's chair, Gerald E. Galloway, Jr.). The report recommended a sharing of responsibility for floodplain management among federal, state, and local officials and for restrictions on developments in floodplains.

Although these national reports had well-justified and comprehensive recommendations regarding levees, at that time there was little appetite for creating a levee safety program on a national scale. Part of the complacency was related to a misunderstanding of flood risk by decision makers and the general public. Some believed that a 1%-annual-chance (i.e., 100-year) level of flood protection corresponded to a high level of flood protection, perhaps meaning that a flood would not occur for another 100 years. In actuality, a 100-year level of flood protection means that there is a 26% chance of flooding during the 30- year life of a typical mortgage. Even a 200-year level of flood protection corresponds to a 14% chance of flooding over a 30-year period. These are actually high levels of risk considering that playing one round of Russian Roulette is comparable to a 17% chance of disaster. It is not until the 500-year level of flood protection is reached that the chance of flooding starts getting down to a relatively small chance (i.e., approximately 6% over a 30-year period).

Hurricanes Katrina and Rita (2005) in the Gulf Coast, changed everything. With economic damages estimated to be more than $200 billion dollars and a loss of life of more than 1,800 persons, the role of levees in providing for public safety and flood risk management was again prominently thrust back into the national spotlight. In the midst of an unprecedented federal investment in levee infrastructure and flood insurance in the greater New Orleans area, Congress passed the Water Resources Development Act of 2007 (Public Law No. 100-114), a key element of which was Title IX, also known as the National Levee Safety Act. The Act sought to develop basic information on federal levees (database, inventory, inspection, and assessments of levees). It also called for a National Committee on Levee Safety charged with developing recommendations for establishing a National Levee Safety Program. Later in 2008, the flooding and breaching of levees in the Midwest reinforced the sense of urgency. The National Committee on Levee Safety established in the 2007 WRDA legislation began its efforts in the fall of 2008.

The Moving Ahead for Progress in the 21st Century Act (Public Law No. 112-141, 126 Stat. 405 (2012), called for USACE and FEMA to align agency processes to allow interchangeable use of information collected for USCAE's Inspection of Completed Works Program and FEMA's National Flood Insurance Program. In 2013, a joint USACE and FEMA taskforce determined that under certain circumstances, USACE risk assessments of levees conducted under the agency's Levee Safety Program could satisfy aspects of levee accreditation under FEMA's National Flood Insurance Program. The effort culminated in a memorandum of understanding signed by USACE and FEMA in which USACE agreed, among other things, to provide FEMA with risk assessment results, and FEMA agreed to accept and consider USACE results, when possible.

In June 2014, the Water Resources Reform and Development Act (WRRDA) of 2014 was enacted (Public Law No. 113-121, 128 Stat. 1193). This act amended portions of the Water Resources and Development Act of 2007 and also required USACE and FEMA to take the lead in implementing certain key national levee-safety-related activities. More specifically, it required continued development of a national levee inventory, and authorized the implementation of a National Levee Safety Program to accomplish the following tasks:

- Develop voluntary national levee-safety guidelines: The voluntary national levee-safety guidelines are intended to be comprehensive standards that are available for use by all federal, state, and local agencies as well as tribes. Under the act, the voluntary guidelines are also expected to address activities and practices by states, local governments, tribes, and private entities to safely build, regulate, operate, and maintain a wide range of levee types, canal structures, and related facilities. The guidelines are also expected to address federal activities—including levee inspection, levee rehabilitation, local floodplain management, and public education and training—that facilitate state efforts to develop and implement effective state programs for levee safety.

- Adopt a hazard potential classification system: A hazard-potential classification system, as described by the National Committee on Levee Safety in its 2009 draft report, would be a first step in identifying and prioritizing hazards in leveed areas and is to be based solely on the potential consequences associated with a levee's failure, as opposed to the likelihood or probability of a levee failure. The act provides for such a system to be considered in the development of the voluntary national levee safety guidelines. This system is to be consistent with the USACE's levee-safety action-classification tool, which ranks levees based on their likelihood of flooding and the associated consequences. According to USACE officials, the tool is currently being used on levees within the USACE's Levee Safety program.

- Provide technical assistance and materials: The agencies are to provide technical assistance and training to help promote levee safety and assist states, communities, and levee owners in (1) developing levee safety programs; (2) identifying and reducing flood risks associated with levees; and (3) identifying local actions that may be carried out to reduce flood risks in leveed areas.

- Provide public education and promote awareness: To improve public understanding of the role of levees, the agencies are to carry out public education and awareness efforts about the risks associated with living in leveed areas. Education and awareness efforts are to be directed particularly toward individuals living in leveed areas. These efforts must also promote consistency in how information about levee-related risks is communicated at the state and local level and shared among federal agencies.

- Develop guidelines and provide assistance for a levee rehabilitation assistance program. This program is to provide assistance to states, local governments, and tribes related to addressing flood mitigation activities that result in an overall reduction of flood risk.22 USACE, in consultation with FEMA, is to develop guidelines for floodplain management plans that program participants are required to prepare to reduce the impacts of future floods in areas with levees. Assistance provided under the program may be used for any rehabilitation activity to maximize risk reduction associated with levees that are (1) under a participating state or tribal levee-safety program and (2) not federally operated and maintained.
  To be eligible, applicants are expected to comply with all applicable federal floodplain management and flood insurance programs, have a floodplain management plan, have a hazard mitigation plan that includes all levee risks, and act in accordance with the voluntary national levee safety guidelines

References for Section 12.4

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- United States Army Corps of Engineers and Federal Emergency Management Agency, Flood Protection Structure Accreditation Task Force: Final Report (November 2013).
- Memorandum of Understanding between the Federal Emergency Management Agency and the United States Army Corps of Engineers for Alignment of Levee Activities, Information, and Messaging (Nov. 13, 2014).

12.5 Guidelines and good practices

The standard of technical care is primarily established through various publications (Engineering Manuals-EM, Engineering Regulations-ER, Engineering Circulars-EC, and Engineering Technical Letters-ETL) by the U.S. Army Corps of Engineers (USACE). In fact, in the Draft Recommendations for a National Levee Safety Program (a report by the US National Committee on Levee Safety to the US Congress in 2009) a recommendation was made that USACE should be given the lead responsibility and funding to develop, maintain, and periodically update technical assistance materials dealing with state and national levee safety programs and the physical integrity of levees (this has not yet been implemented into law).

Arguably the central USACE guidance document is EM 1110-2-1913 Design, Construction and Evaluation of Levees (http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1913.pdf). This EM has undergone significant revision and is presently being updated by USACE to overcome two main drawbacks: (1) heavy focus on Mississippi Rivers and Tributaries (MRT) levees, and (2) adherence to mostly rigid deterministic performance-based standards. The updated manual will encompass a broader perspective of regional practices, and use of risk-based potential failure modes to drive design and performance objectives.

Some regional differences in practice exist and are promulgated within USACE by unique practices tailored by Divisions and Districts (see “Geotechnical Levee Practice” USACE Sacramento District). Some states adopt or modify their own specific technical guidelines and practices according to the unique issues they may face These regional differences are driven by many factors, such as those which influence loading conditions (e.g. riverine versus coastal levees), geologic variability (which influence not only foundation conditions, but often borrow material available to construct levees), climate and hydrology (arid versus temperate environments), as well as environmental factors (such as the management of vegetation).

An example of focused regional guidance is the Hurricane and Storm Damage Risk Reduction System (HSDRRS) Design Guidelines that was developed to compile design best practices, guidelines and standards for those engaged (USACE and the A/E community) on the rebuilding efforts post-Katrina and Rita in 2005 (http://www.mvn.usace.army.mil/Portals/56/docs/engineering/HurrGuide/EntireDocument.pdf). This document was obviously focused particularly on coastal levee issues. It was updated to account for new research and changes in the state of practice spurred by the high visibility of the failures and impacts identified through numerous forensic investigations

1) Specific Guidance for Various life cycle phases (in addition to those noted previously) Planning documents for formulation, evaluation and implementation:
   a. EM 1110-2-1619 – Risk-based Analysis for Flood Damage Reduction Studies
   b. ER 1105-2-101 – Risk Analysis for Flood Damage Reduction Studies
2) Design concepts in the past based primarily on economic drivers; current design based on life safety and economics and moving towards a risk-informed framework based on potential failure modes (PFM) evaluation:
   a. California Department of Water Resources (DWR) Urban Levee Design Criteria
   b. ER 1110-2-8159 Life Cycle Design and Performance
   c. ER 1110-2-1150 Engineering and Design for Civil Works Projects
   d. ETL 1110-2-555 Design Guidance on Levees
   e. EM 1110-2-2502 Retaining Walls and Floodwalls
3) Construction
   a. NA
4) Operation and Maintenance (O&M), including inspections and floodfighting:
   a. ER 1130-2-530 Flood Control Operations and Maintenance Policies
   b. Levee Owner’s Manual for Non-Federal Flood Control Works, The Rehabilitation and Inspection Program (RIP) Public Law (PL) 84-99
5) Modifications made to USACE projects follow the technical protocols addressed herein, following policy guidance:
   a. EC 1165-2-216 Policy and Procedures Guidance for Processing Requests to Alter USACE Civil Works Projects Pursuant to 33 US Code (USC) Section 408
   b. ER 1165-2-119 Modifications to Completed Projects
6) Decommissioning
   a. NA
7) Miscellaneous (vegetation, certification/evaluation for 33 CFR 65.10 criteria applied to FEMA NFIP)
   a. ETL 1110-2-583 Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures
   b. EC 1110-2-6067 USACE Process for the National Flood Insurance Program (NFIP) Levee System Evaluation

12.6 Common practices during Levee Life Cycle

12.6.1 Planning Practices

Planning is a creative process requiring knowledge of water resources laws and regulations, public involvement methods and processes, engineering, economics and social impacts of water resources projects. Planners must respond to complex and interrelated processes of social, economic, cultural, environmental and political change at every scale from the local to the global and be able to integrate these factors in the formulation of solutions to water resources problems and opportunities. Their specialized expertise derives from their ability to relate scientific and technical knowledge to action in the public domain. We should remember the importance to implement, while planning, the concept of insuring:

- Safety (during construction, for the structures and for the public)
- Quality (of any type of work and implementation applied)
- Durability (in order to extend the life of the work done and to reduce future maintenance)

The relation and application of the above concepts, and in all the work described here below, will result in promoting and implementing sustainability.

Planning comprises all the work associated with the six-step planning process:

1) Specify Problems and Opportunities - Identifying the problems and opportunities is the most important step in the planning process. Once the problems and opportunities are described, the next task is to define the objectives and constraints that will guide efforts to solve those problems and achieve those opportunities.
2) Inventory and Forecast Conditions - the information gathering step. It is, perhaps, the most familiar planning task. Gathering information about historic and existing conditions produces an inventory. Gathering information about potential future conditions requires forecasts. Inventories and forecasts are generally concerned with the conditions of resources that will be affected by solutions to the problems. These resources may be natural, economic, or social. Their precise identities vary from study to study. The one thing they all have in common is that they will help shape the plans to be considered, or they will be affected, intentionally or unintentionally, by one or more of the plans to be considered. Inventory should include the analysis and the understanding of what is the missing data/information required which could have possibly prevented the event(s).
3) Formulate Alternative Plans - Plan formulation is the process of identifying specific ways to achieve planning objectives while avoiding constraints so as to solve the problems and realize the opportunities that got this whole investigation started. This step of the planning process produces solutions that achieve all or part of one or more of your planning objectives. Solutions are alternative plans built from management measures.
4) Evaluate Effects of Alternative Plans - The evaluation step tells what difference each plan can make. That difference is quantified by comparing without project and with project conditions to identify the effects of alternative plans. The essential purpose of the evaluation step is to determine whether or not a plan formulated is worthy of further consideration. It is a qualifying step. Each plan is held up to a situation-specific set of criteria and evaluated whether it deserves further consideration or not.
5) Compare Alternative Plans - Compare the effects of the various plans and make trades among the differences observed. The purpose of plan comparison is to identify the most important effects, and to compare the plans against one another across those effects. Ideally, the comparison will conclude with a ranking of plans or some identification of advantages and disadvantages of each plan for use by decision makers.
6) Select Recommended Plan - Decision makers must purposefully choose the single best alternative future path from among all those that have been considered.
7) Insure that the Recommended Plan for the future includes the possibility to obtain all data required to avoid new events and to control the integrity and status/capabilities of the structure(s) involved. Most of the information missed in the past can now be collected during construction/implementation by requesting the use of technologies, equipment, tools and instrumentation that is able to provide real time control of the quality of the work performed.

   The plan that is selected is most commonly that which provides the greatest net economic benefit consistent with the competing interest for protection of lives, property and the environment. Plans and their effects should be examined to determine the various risks and the uncertainty inherent in the data or various assumptions of future economic, demographic, social, attitudinal, environmental, and technological trends. A limited number of reasonable alternative forecasts that would, if realized, appreciably affect plan design should be considered.

12.6.2 Design Practices

Levees have traditionally been designed using deterministic analyses and applying minimum criteria (i.e., factors of safety). The selection of minimum criteria for levee design has changed little since 1978, likely due to a general history of acceptable performance. What has changed are the tools used for design, the continued improvement in the understanding of failure modes, and the characterization of levee reliability and system risk. This progress is pushing the profession toward deterministic criteria that have a general history of successful performance while incorporating probabilistic methods to capture uncertainty and allow designers a process for using lower or higher factors of safety based on project risk. For levee design and construction activities, risks associated with levee breach prior to overtopping, malfunction of levee system components, and levee overtopping with breach inundation scenarios should all be considered when selecting and evaluating design components. Risk associated with levee overtopping without breach are also considered during the planning process prior to levee design and construction activities.

The traditional factors of safety are now applied at the flood load associated with the design water surface elevation (DWSE) since that elevation is associated with 100% economic benefits. Unlike structural criteria, where factors of safety are commonly associated with an annual exceedance probability (AEP) of loading, the geotechnical factors of safety are applied to clearly defined elevations associated with the DWSE or project levee grade determined by hydrology, hydraulics and economics. The DWSE corresponds to and is consistent with hydraulics and hydrology design, economics and planning risk processes for new levee design. Levees designed and built for water loading to this elevation would be required to have a very small probability of failure (i.e., should meet all typical standards for flood loading up to the DWSE). In the U.S. Army Corps of Engineers (USACE), up-to-date planning and design of levee projects, will require all forms of uncertainty to be explicitly addressed in the risk-based planning process, resulting in the DWSE with no implicit freeboard. All water loadings up to the DWSE are expected to result in very low likelihood of unsatisfactory performance that could lead to breach (i.e., annual chance exceedance for loading and failure for all water levels up to the DWSE (i.e., prior to overtopping) is very small, approximately less than 1E-04). For geotechnical analysis, the DWSE will be used in all design analyses to assess configurations and features necessary to meet standard design criteria.

The top of barrier associated with the DWSE, plus superiority, plus over-wash height (or wave run up overbuild) is termed the project (final) levee grade. Where superiority and over-wash height are zero, the final levee grade equals the DWSE. Levees designed in conjunction with riverine projects may include superiority (extra levee height to ensure overtopping at a predefined location). Levees designed in conjunction with coastal projects may have an increased top of levee elevation in excess of the DWSE to keep wave over-wash (volume of water from wave run up that reaches the dry side) below some acceptable limit. Levees constructed for limiting over-wash may be loaded to a still water level at the DWSE plus wave run up overbuild.

Current modern levee design in the U.S. should account for the most commonly defined failure modes. Of course, conditions for every system are unique and designers are encouraged to refine failure modes that may be unique to their project and region. General failure modes that should be considered are: internal erosion; stability; erosion; seismic initiated; malfunction of levee system components; and construction related failure modes.

12.6.3 Operation and Maintenance Practices

All flood control works (FCWs) must be properly maintained to provide the protection for which they were designed. The owner/operator is solely responsible for ensuring that the FCW is properly maintained and will protect lives and property. Proper maintenance of the FCW must be taken very seriously, and local plans and budgets need to be structured so that the maintenance of each project feature is carried out on a regular and continual basis. In addition to providing for usual operations and maintenance expenses, this budget needs to account for the replacement of more expensive project components such as pumps, motors, gates, and corrugated metal pipes as they age and come to the end of their design life. There are many ongoing requirements of which the owner/operator should be aware. Maintenance of the FCW should contain activities to address the following; erosion, encroachments, slope stability, removal of debris, animal control, riprap revetments and banks, vegetation, cracking, ruts and depressions, under-seepage control berms, excavations, utilities, relief wells and toe drains, seepage and sandboils, closure structures, concrete surfaces, internal drainage systems, pump stations, channels, basins, and floodways.

The owner/operator is responsible for developing and maintaining a basic flood response plan. Owners/operators of flood control works are responsible for project maintenance and flood fighting activities during high water events. To be ready for these tasks, sponsors are responsible for establishing flood fight plans, conducting training, stockpiling needed materials, and for other flood preparations. It is an owner/operators responsibility to develop and maintain a minimal level of written plans, and to keep those plans up to date. The extent of the plans depends on the specific FCW. Large systems with multiple pumps and drains would require more detailed plans than smaller systems. Documented plans ensure that the information needed to address known problem areas will be available during a flood, even if the main supervisor is unavailable. As a minimum, every owner/operator should maintain at least an organizational chart or roster, and lists or maps of important project features. The owner/operator is responsible for training personnel to operate, maintain, and patrol the FCW. They are also encouraged to hold training or flood control exercises at least once a year. There are many reasons to hold these exercises.

There are several additional requirements that the owner/operator should be aware of, including the following. A pre-flood-season inspection program should be in place for the FCW. There should be frequent and ongoing activities to both educate and involve the public in the FCW related activities. There should be awareness and interaction with other FCW, if they are part of an overall protective system. There should be an active program of keeping accurate records of all activities related to the FCW including maintenance, repairs, flood fighting events, etc.

12.6.4 Modification Practices

The general procedure to follow in seeking to modify an existing levee are as follows. The requestor should ensure proper coordination with all necessary entities. Requestor should also show that the proposed alteration does not negatively impact or impair current usefulness and benefits of the existing project, which includes the project's authorized purpose, and is not injurious to the public.

Modifications to existing levees should contain an evaluation process, verification that the modification meets existing design standards, and updated operations and maintenance procedures that may be relevant to consider for alterations to the levee, floodwall, or channel project. Each modification project should clearly identify the existing condition of the project being altered and include plan, profile and design details of the proposed modification in relation to the existing project. At a minimum any modification project should have sufficient documentation to support and defend the proposed effort. This would include:

- Technical analysis and design – this is necessary to assist in the decision making process for the requested modification design. Typically plans are submitted at various stages of completion (i.e. 60% and 95%) to provide for interaction between the requestor and approver. The design should show clear identification of existing conditions and proposed alterations.
- Geotechnical and structural - considerations and assessment of impacts of proposed modifications to the geotechnical or structural integrity of the existing system must be shown by the requestor.
- Hydrologic and hydraulics system performance analysis - The purpose of a hydrologic and hydraulics system performance analysis is to determine the potential hydrologic and hydraulics impacts of proposed alterations. The proposer should determine the appropriate scope of analysis based on the complexity of the proposed alteration.

- Environmental compliance - the requester is responsible for providing all information as necessary to satisfy all applicable federal laws, executive orders, regulations, policies, and ordinances.
- Water control management plans – any impacts or changes to the existing plans for water control and management must be clearly detailed by the requestor.
- Operations, maintenance and flood fighting - requesters must identify any operations and maintenance requirements needed throughout the life of the proposed alteration and the responsible entity for the operations and maintenance into the future.
- Review plan – the requestor should make arrangements with the approver the level of review necessary for the proposed alteration plans.
- Implementation of any advanced Information Management Data System in order to insure quality during the modification and continue control of the integrity of the structure(s) part of the work performed.

12.6.5 Construction Practices

Levee construction activities vary based on specific project requirements. Construction of a levee involves many different engineering and construction disciplines. The definition of the construction process requires input and coordination of responsible professionals with experience in construction of levees. Construction issues and challenges are best resolved by an experienced multi-disciplinary team that includes the hydraulic and geotechnical engineers from the design team, the owner designated project manager, the construction manager representing the contractor, contractor's personnel with experience in heavy construction, and input from local government agencies familiar with local regulations and environmental restrictions. Thus, levee project requirements should be communicated clearly and comprehensively in the design/bid package to the contractor and routinely reviewed during the levee construction activity. Successful levee construction requires a coordinated team effort including the project delivery team (PDT), construction inspectors (i.e., quality assurance), local sponsors, and the contractor.

Levee embankments can be constructed utilizing different methods and composed of impervious or semi-pervious materials. The type of allowed construction methods are detailed following.

Compacted – Commonly used method to form the central portion of the levee embankment. The method of construction specifies the water content range with respect to standard effort optimum water content, placed in lift thicknesses of 152 – 228mm, utilizing compaction equipment, specified passes to obtain target percent compaction to verified minimum required density.

Semi-compacted – This is the most common type of levee construction practice. The method of construction specifies compaction of fill materials at their natural water content, placed in lifts of 305mm, compacted by either controlled movement of hauling and spreading equipment or by a few passes of compaction equipment, minimum verification of compaction.

Levee construction includes the important process of defining the foundation/consolidation requirements and if any type of seepage/piping issue needs to be addressed.

Basic foundation preparation and treatment (clearing, grubbing, stripping, disposal of debris, exploration trench, dewatering, and final foundation preparation). Construction also includes methods of improving stability for levees located on foundation soils that cannot support the levee embankment because of inadequate shear strength. These methods include excavation and replacement, displacement, stage construction and densification.

As a general rule levee embankments are constructed as homogeneous sections because zoning is usually neither necessary nor practicable. However, where materials of varying permeability are encountered in borrow areas, the more impervious materials should be placed toward the riverside of the embankment and the more pervious material toward the landside slope. Where required to improve under-seepage conditions, landside berms should be constructed of the most pervious material available and riverside berms of the more impervious materials. Where impervious materials are scarce, and the major portion of the embankment must be built of pervious material, a central impervious core can be specified or, as is more often done, the riverside slope of the embankment can be covered with a thick layer of impervious material. The latter is generally more economical than a

central impervious core and, in most cases, is entirely adequate. Where seepage conditions are encountered it will be necessary to evaluate the required technology to construct the needed cut-off wall. Where possible liquefaction conditions are recorded, ground consolidation/improvement technology should be evaluated.
It is often concluded that low cost protection, such as grass cover, will be adequate in general for a levee reach, but with a realization that there may be limited areas where the need for greater protection may develop under infrequent circumstances. If the chances of serious damage to the levee in such areas are remote, good engineering practice would be to provide such increased protection only if and when actual problems develop.

12.7 Critical knowledge and data gaps; critical research needs

12.7.1 Internal Erosion

Failure modes associated with internal erosion processes are typically high risk failure modes due to the fact that failure is likely to occur at flood stages below the design flood. This scenario is particularly dangerous as flood fighting actions and evacuations may not be enacted due to the perception of additional flood storage capacity. Furthermore, managing risks due to internal erosion is difficult due to the fact that nearly all locations along a levee are vulnerable to internal erosion failure modes. For these reasons, significant research is still needed to develop reliable methods for predicting where internal erosion may occur and how quickly erosion will develop. The following paragraphs discuss the types of internal erosion of highest concern, what knowledge gaps remain regarding these failure modes, and the research that is needed to address these knowledge gaps.

Types of Internal Erosion: As previously mentioned, there are four types of internal erosion: concentrated leak erosion, backward erosion piping, contact erosion, and internal instability (suffusion/suffusion). Backward erosion piping and concentrated leak erosion are the two internal erosion mechanisms of primary concern in the United States for levees. Backward erosion piping is the most prevalent mechanism spatially making it a difficult failure mode to manage. Concentrated leak erosion is of particular concern near utility crossings and closure structures.
Knowledge Gaps: Currently, it is not possible to reliably predict where and when backward erosion piping and concentrated leak erosion will occur. Because of this, past flood performance is used in the U.S. as the primary indicator of where high risk sites exist. This has proven effective over the last 100 years; however, it neglects the temporal aspects of risk due to changes in infrastructure and hydrologic loads. Reliable techniques are needed for determining where internal erosion will occur.
In addition to identifying where internal erosion will occur, it is necessary to be able to predict how quickly erosion related failure modes will develop. Transient models for backward erosion piping related failure modes do not currently exist. Identifying locations susceptible to rapid failure by internal erosion is critical as these sites pose the greatest risks in terms of both life loss and economic damages.
Research Needs: Previous attempts to develop predictive methods for backward erosion piping have all proven to be unsatisfactory. A primary reason previous methods have not worked well is the fact that the physical processes of backward erosion piping have not been well understood. Only recently, (CritVan Beek, 2015) has a clear understanding of the processes at the laboratory scale been developed. Further research is needed to develop a thorough understanding of the physics of internal erosion processes. This is required in order to (1) assess the probability of failure quantitatively, (2) allow for the temporal aspects of the process to be considered (i.e. – is it slow enough to be able to detect and react during a single flood?), and (3) design monitoring systems to provide greater opportunities for early detection. The physics of internal erosion processes can be investigated through laboratory research and numerical modelling. Once the processes are understood in the lab, the field conditions conducive to piping can begin to be quantitatively assessed.
While a complete knowledge of the physics of internal erosion may allow for quantitative assessment of risk, it is not the only means of identifying high risk sites. Research should also be conducted on the

development of empirically based assessment methods for identifying whether risks due to internal erosion are high, medium, or low at particular sites. Historically speaking, this approach has been difficult in the U.S. due to the inability to nationally collect consistent performance data, especially for "near-failure" incidents. In order to develop improved, empirical models for internal erosion, it is necessary to collect detailed information regarding site characteristics that may influence the process. Items of particular interest are the soil types, soil stratigraphy, soil grain size distributions, load duration, and observations regarding the temporal development of erosion. It is currently uncommon for this type of information to be collected in the U.S. As the accuracy of empirical methods is dependent on the quality of the data upon which they are based, it is imperative that detailed data begin to be collected for the development of empirically based assessment methods.

12.7.2 Overtopping

U.S. levee design has been historically controlled by flood hazard rather than flood risk. Because of this, society has accepted the flood risk associated with certain flood frequencies. Even though levee overtopping is the most common failure mode for levees, it is expected to occur and rather unlikely that significant structural measures will be taken to reduce levee overtopping related flood risks for most U.S. levee systems. Therefore, research regarding overtopping must be focused on improving the performance of structures during overtopping rather than preventing overtopping. Improving overtopping performance, and thereby reducing the likelihood of complete breach, leads to reduced damages due to interior flooding and lower risks.
Research Needs: With regards to overtopping resiliency and overtopping related flood risks, research should be conducted on the following items:

- Overtopping Resiliency: Research must be conducted on the development of economical measures (both temporary and permanent) that can be used to decrease structural damage during overtopping. While previous research has been conducted looking at the use of vegetation, geogrids, geofabrics, slope pavements (concrete, asphalt, matting, etc.), and treated soils to prevent erosion during overtopping, a formal guidance document does not exist to aide in evaluation and selection of appropriate measures. Guidance is needed that compares cost, performance, installation time (for temporary measures), and reliability for various alternatives. This is an important research need as less damage during overtopping (more resilient levees) will lead to lower consequences in many cases.
- Overtopping Warning Systems: Overtopping is a failure mode that is easily monitored through instrumentation. Research is needed to develop and test overtopping notification systems. In particular, the societal response (locally) to the information provided by warning systems is needed.
- Informed Societal Perspective: While it has been stated that a certain level of overtopping hazard is accepted by society, it has also been shown through recent studies (sources?) that many individuals in the US are entirely unaware of the flood hazard to which they are exposed. Research is needed to determine if society and government officials are truly accepting of current flood risk management practice when informed of current risk, past economic damages incurred, etc.

12.7.3 Other Data Gaps

In addition to the major research needs identified above, research should also be conducted on the Bayesian approaches to probabilistic site characterization to improve the professions ability to manage flood related risk associated with levees.

13 Conclusions

- Levee infrastructure

This reportprovides an overview about levees and flood defences in 10 European countries and the USA, representing thousands of kilometres of levees.

Most levees are situated along rivers, but in some countries (especially in Western Europe), a significant part is along the coast or along lakes. Urban levees and floodwalls, and hydraulic structures represent a smaller but still important fraction, because they protect many people as well as valuable assets and properties.

Typical levee heights are within the range of a few metres, but occasionally can exceed 10 metres in height and therefore, coming close to the dimensions of dams

- Failure, hazard and floods

Several countries have experienced levee failures in the last 50 years. Common failure causes are overtopping, internal erosion, problems with conduits crossing through levees, problems with transition structures, slope sliding and in one occasion even due to drought. In some cases, soil subsidence (for example due to drainage or mining) may also increase hazard and risk.

In the past, several catastrophic levee failures have occurred. Today, one would expect that low consequence failures would be the most common, especially because stricter safety standards and stronger flood defences are becoming more common for high-risk areas. Nevertheless, some recent floods demonstrated that catastrophic flooding with significant loss of life is still a significant possibility, and a major risk. In fact, is is estimated that a minimum of 50 million people in Europe are at risk of flooding, and many of those are protected by levees. The protected economic value is over 2000 billion Euros. Worldwide, 15% of global population is expected to live in flood-prone areas by 2050.

In the period 1950-2005, over 45 major flood events occurred across Europe, each causing a damage of at least 0,005 % of the full European Gross Domestic product or at least 70 fatalities. Recent floods in central Europe led to several billion Euros of damage.

- Legislation and governance

Levees often are not explicitly addressed in the deliverables required by the EU Floods Directive as these deliverables often focus on a general policy level. However, in some countries, the Floods Directive was an incentive for revised safety standards and/or reinforcement works.

In several countries, dams and levees fall under the same legislation (or legislative framework) and thus under the same or similar regulations. This clearly demonstrates the need to verify whether and to what extent general guidelines and best practices for dams are applicable to levees, and vice versa.

Safety standards often are (or used to be) in the order of 1/100 yr, but especially in high-risk areas, the degree of protection tends to be raised because of risk and/or cost-benefit considerations, and standards in the order of 1/1000 or 1/10000 yr are becoming common.

Levee-related governance (who is responsible for what) is quite complex in many countries, with significant differences among countries, or even amongst states within federal countries. Despite the differences, many stakeholders are often involved.

Some, but certainly not all, countries have central levee registers, along with their dam registers.

- Current practices

Most countries largely rely on national guidelines, often inspired by international best-practices. ICOLD Bulletins and the International Levee Handbook are rarely used directly.

Levee inspections and safety assessments are scheduled less frequently and/or less systematically than for large dams, somewhat in line with the ICOLD experiences for small dams.

Finally, it is interesting to note that levee maintenance is done at a relatively low financial cost. On the other hand, (re)construction of levees is often relatively expensive, in the order of 1-2 million Euro per kilometer and more in complex/urban areas .

A brief summary of *facts and figures per country* is given below followed by overview tables.

Belgium

- Up to 700 km of (large) levees of which 10% along the coast, 10% along rivers and 80% under tidal conditions
- Up to 1 million people are protected by water defences to extreme events ranging from 1/500 to 1/10000 years
- Near-failures from the last decades are slowly raising awareness on (improved) levee management among stakeholders
- Agencies within the ministry of mobility and public works take care of the levee management within the framework of the EU Directives
- (Intern)national design guides are used

Czech Republic

- About 4000 km of levees including urban floodwalls up to which are often used; the number of structures is not identified but probably several hundreds,
- Mostly up to 4 m high, with (required) crest width > 3m and inner slopes up to about 1:2 (outer about 1:3)
- 90 % along rivers, 10% along streams and/or torrents
- In 16 years time, 4 major floods with return periods > 500 years, causing about 130 fatalities and order 6 billion Euro damage.
- Failures mostly due to overtopping and internal erosion, many a times close to conduits in the levee. Until 2004 failure rate in Morava river basin order 0,003 failures/km/yr.
- Safety standard not unique, according to the property in floodplain, determined by the cost benefit analysis using risk approaches, (?) often in the order of 1/100, recently raised up to 1/10000 when high risk.
- Regulations spread across several laws, standards and guidelines, dams and levees fall under same legislation.
- Key facts governance - levee owners, state interventions, key role of river agencies.
- Guidelines - mostly national technical standards and national guidelines; Levee handbook and ICOLD Bulletins generally not directly applied
- Main knowledge gap related to lack of central levee register.

England

- 2.4 million properties and a significant amount of critical infrastructure at risk from sea or river flooding (and 3 million more by surface runoff), representing an annual economic consequences of river/coastal flooding risk about 960 million pound (slightly over 1 billion Euro).
- About 8000 km of levees of 1-6 m height, and 22000 hydraulic / flood protection structures
- 70% of them along rivers, another 18% along estuaries and 10 % along the coast
- Safety requirements up to 1/1000yr for large scale high hazard (depending on cost-benefit), typically 1/100yr or 1/200yr for most, and 1/5yr - 1/100yr for low risk areas only.
- Some failures during the winters of 2013/2014 and 2015/2016, due to overtopping and inner slope erosion and along transitions. No lives lost, but some people evacuated. Improvements implemented or under investigation.
- Levees along sea and main rivers managed by state (Environment Agency and others), the remaining 50% by third (public or private) parties
- Dam legislation appears to be more specific than levee legislation.
- There are central registers for dams, and also for some levees.
- Common practices are annual risk-based maintenance programmes, risk-based inspections every 0,5-5 years (depending on risk) and flood event management. Reinforcement cost is slightly less than 1 MEuro/km

- Critical knowledge gaps relate to climate change/adaptation, levee performance and failure modes (especially near transitions), predicting life stage of levee and vegetation management.

Finland

- About 80 registered levees
- 31 levees have been classified according to the Dam Safety Act, which formed 70 km of classified levees.
- Most levees protect farm land from rivers, also some sea levees and urban levees
- The most important levee (at Pori) protects 15000 people and 3 million Euro in assets
- Many levees are now being constructed or improved in response to the EU Floods Directive, safety standards are also upgraded to typically 1/100 yr.
- Damage potential for a 1/250 yr flood would be about 550 mln Euro
- Large (springtime/snow-melt) river floods in 1953, 1966, 1984 and 2000 with up to 5 million Euro damage; large (1/30 yr) storm surge in Helsinki in 2005.
- Dams and levees have common legislation/regulation

France

- About 9000 km of levees (roughly 90% inland and 10% coastal)
- Usually from locally available earth material, height usually up to 6 m.
- Annual flood damage order 1 billion Euro/yr, roughly 25% insured
- 18 million people live in potential flood hazard areas, 2 million people and 20000 km2 (roughly 3% of France) are protected by major flood protection systems.
- Some recent flood defence failures, but no failures until 1993
- Levees have no explicit role in Floods Directive implementation
- Similar legislation for levees, dams and other protection structures
- Common practices and obligations depend on levee type/class (depending on height and protected population)
- Many levees to be inspected for first time; for high-risk levees in-depth inspections/assessments every 1-10 yrs.
- Governance: various parties involved: from state to municipality to home/ground owner
- No prescriptive guidelines, but various informal guidance documents
- Annual investment typically 7.5 to 10.4 kEuro/km, annual maintenance typically 4.4 to 8.5 kEuro/km, annual management typically 2 to 3.8 kEuro/km

Germany

- In Germany exist some 10 000 km of levees, and thousands of adjacent structures.
- It is estimated that about 20% of the levees are coastal and 80% fluvial.
- The levees protect over 12 million people and at least 2 billion Euro in asset value.
- The safety standards are set by the actual standard DIN 19712 and the DWA Guideline 507-1 as well as the EAU-Recommendations for the coast. The level of protection for densily inhabitated areas is normally 1/100. More values are given in Table D-5.
- Recent levee failures occurred e.g. in 1997 at the Odra river and 2002 and 2013 at the Elbe and Danube.
- The standard DIN 19712 and the DWA Guideline 507-1 as well as the EAU-Recommendations are the main guideline documents for levee planning, design and assessment. ICOLD Bulletins and the International Levee Handbook may be consulted but play no key role.
- Governance reflects the fact that Germany consists of 16 Länder in which governance may differ
- Key knowledge gaps: flood risk prediction and mapping using the actual condition of levees, and knowing the levee and its underground in greater detail.

Hungary

- 25% of country and population flood prone
- 4200 km of (river) levees

Italy

- Features of the levee system
    - Po River: 650 km, 141 tributaries. Po District: 2300 km of levees of category 2.
    - Eastern Alps District: Adige rive: 410 km + 5 main rivers flowing into the Adriatic sea. 6300 km of levees of all categories.
    - The levees in the medium and lower course of the Po and Adige river have wide cross sections reinforced across the years, the other rivers in northern Italy have much narrower cross sections. The construction materials mostly depend on the geological context: mountain valleys, upper plain or lower plain.
- Residual risk: For a medium probability event, 8% of the national territory would be flooded. In this territory live 6 ml people (10% of the population) and there are 600 000 productive units.
- Recent failures
    - Veneto Region, 2010: 9 levee breaches, 426 ml euro damage. Failure mechanisms: overtopping, rapid drawdown, soft-hard structure transition.
    - Secchia River, Po district, 2014: 500 million euro estimated damage. Failure mechanism: instability promoted by animal burrows.
- Key players
    - Planning: District Authorities; however, since these are not established yet, the Basin Authorities of national relevance coordinate the planning at district level.
    - Administration and management of flood defenses: Regions + operative structures as: Genio Civile, Civil Protection Agencies, Land Reclamation Consortia, Mountain Basins etc.
    - Administration and management of flood events: Regions, through operative structures as:
        - Decentralized Functional Centers, with function of data analysis, formulation of scenarios and communication of alarms;
        - Hydraulic Territorial Presidio with function of levee patrolling and first interventions;
        - Other stakeholders, among which dam managers.
    - Management of flood emergencies: Regions are the relevant Authorities of Civil Protection for flood emergencies. Municipalities should be provided of an emergency plan, including the actions to take in case of flood emergency. Mayors the most important Authorities of Civil protection at the municipality level. The President of the Region can ask the Prime Minister to declare the national emergency state.

The Netherlands

- About 3500 km of primary flood defence; about 3000 km of levee, typically 3-10 m high (average ~6m); slopes mainly order 1:3, often interrupted with a berm
- In addition about 1500 hydraulic structures as primary flood defence
- 30% along rivers, 30% estuaries, remainder along lakes and coast
- Former safety standards by law: withstand 1/250 to 1/10000 per year water level; nearly two-thirds of defences are OK
- New/current safety standards by law: 1/300 to 1/100000 per year flood probability; probably more stringent.
- 60% of land and about 70% of population/economy at risk without levees
- This is 12 million people or 400-500 billion Euro of yearly economic production, and at least one trillion of protected property value.
- Present actual protection level about 1/1000 per year, but this used to be less
- 6-7 floods or near-failures in last century, typically during 1/100 yr events. Various causes (overtopping and slope failure coastal levees, piping for levees, as well as failure due to non-flood causes like water supply pipes and drought, ..)

- Strong reliance on protection (by levees), and on standardised (and often model-based) approach for safety assessment, design, and to some extent also daily management
- Damage cost is limited due to strong protection, national reinforcement budget is 360 million Euro/yr, regular maintenance spending probably less. Typical cost per kilometre is order 50000 Euro/yr for regular (all-in) maintenance and 1-30 million Euro per kilometre for each major upgrading.
- Safety standards included in law, guidelines referred to in general sense
- strong reliance on dedicated national guidelines; the International Levee Handbook is not yet commonly used, and this applies even stronger to the ICOLD-Bulletins

Poland (Answers from Questionnaire)
- In our registry we have 7365 km of levees, 8 gates, 70 pumping stations, 301 dams, 343 weirs, 401 canal locks, 19 levees which are controlled as structure of reservoir
- 90% protects from river hazard, the remainder from lake or sea hazard; in 90% there is only material hazard, the remaining 10% also presents some life hazard.
- Typical levee heights are about 3 metres (1-5)
- There are central dam and levee registers

Slovenia (Answers from Questionnaire)
- Over 100 km of levee and 50 km of flood wall; 100-200 hydraulic structures and 69 dams
- 73% along torrent, 20% along river, 5% along lake, 2% along sea
- Height 1-53 m, medium height 7m (probably including the dams)
- 700000-800000 protected people
- 3% represents a large scale life hazard (if the levee/dam breaks), another 50% represents some life hazard, the remainder material hazard only
- Maintenance cost about 10000-15000 Euro/km

Spain
- Over 1000 large dams, several thousand km of typically 3-5m high levees, especially in Ebro, Duero and Guadiana basins, mostly to protect cultivated areas and small towns
- 2-3 million people at risk from flooding (of which ~300000 from marine flooding), about 10 flood casualties per year and order 800 MEuro yearly damage.
- Marked difference between regulation and practices for dams and levees. Highly regulated for dams, much less so for levees: no official/complete inventory, no specific rules and regulations and often incidental maintenance and quite frequent failures. Guidelines under development as part of the Floods Directive implementation.
- Floodplain restoration gets quite some attention, and levee removal of (obsolete) levees is often part of it.

Switzerland
- There is no central dam/levee register
- All levees are situated along rivers
- Overflow sections to handle overload scenarios are increasingly used
- 1.8 million people live in flood-prone areas
- There are no specific guidelines on design and engineering of flood protection levees
- The required protection levels are defined by protection goal matrices (risk-based assessment)

USA
- A national Levee Register can be found on http://nld.usace.army.mil , but it only covers part of existing levees.
- In total there are probably over 150.000 km of levees in the US
- Many levees have long and complex construction history

- Many levees with safety level equal to the minimum insurance accreditation level of about 1/100yr, due to affordability concerns
- Most high-risk levees constructed by USACE (but often maintained by non-federal entity)
- Major floods occurring every few years, on average
- In 2011 only, over 260 billion $ flood damaged prevented by levees
- Since 1927 a factor 8 return to investment in prevention.
- Long history of flood protection legislation, but some divergence between dam and levee legislation
- USACE has key role in providing (technical) guidance documents
- Key knowledge gaps are internal erosion and overtopping resistance

The results are summarised through the following tables (results taken from the General Report of ICOLD Congress Question Q103 "Small dams and levees" by R. Tourment, Vienna 2018).

Overview table 1 - Portfolios of levees (estimates)

Country	Levees	Protected stakes
Belgium	700 km (large ones only)	1 million people
Czech Republic	4000 km	unreported
England	8000 km	2.4 million properties
Finland	80 registered levees	unreported
France	9000 km	2 million people, 20000 km^2
Germany	10000 km	12 million people, 2 billion €
Hungary	4200 km	unreported
Italy	Uncomplete at nation scale Po river: 650 km Eastern alps district: 6300 km	unreported
Netherlands	3500 km of primary flood defences	12 million people, 400-500 billion € yearly production, 1 trillion € value
Poland	7400 km	unreported
Slovenia	> 100 km	700-800000 people
Spain	Several thousand km	2-3 million people
USA	> 160000 km	Tens of million of people

Overview table 2 - Some recent catastrophic floods involving levees

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

Overview table 3 - Levee regulations and governance in a few countries

Country	Legislation and regulation framework	Governance
Belgium	Levee act from 1979	Clearly organized. Most levees managed by governmental agencies.
Czech Republic	Same as dams	Most levees managed by River Board State agencies
England	Floods and levees, 1991 and 2010. Levee safety same framework as dams	Clearly organized but fragmented
Finland	Levee safety same as dams	Fragmented
France	Similar to dams	Since 2018, flood protection is clearly attributed to the EPCI (a local authority)
Germany	Specific to each State on the basis of national standards (DIN) and guidelines (DWA, BWK)	Depends of the State
Italy	New Technical Norms for Constructions (2008, 2018). Technical Norms for dams do not apply to levees.	Organized by Basin authority, Regions, Autonomous Province but fragmented.
Netherlands	Levees and dams regulated through the Water Act of 2009.	Primary flood defences managed by Water Boards (local authorities); key national flood defences managed by the National Water Authority.
Spain	No specific regulatory framework for levees. Requirements for Local Flood Risk Management Plans may vary for each region.	Fragmented. Organized at River Basin scale.
USA	National levee safety act of 2007 amended in 2014 authorizes a national levee safety program, but it has not been fully implemented	Fragmented National levee safety program amended in 2014 (if implemented) calls for state levee safety programs

14 Recommendations on quoted (research) needs

The following table presents an overview of mutual critical knowledge and data gaps mentioned in this report. Three types of knowledge and data gaps could be distinguished in this report, ie. lacking fundamental insight and understanding, unsuccessful transfer of existing body of knowledge and missing hands-on praticitioners guidance. Depending on the issue, one or more types of gap can be identified, preventing levee managers to be *in control*. It is therefore recommended to elaborate research programs, design effective knowledge transfer channels and/or establish a community of practitioners that address these issues in a progressive way. In addition to guidance through a community of practitioners, it is advised to first define clear responsibilities (and corresponding duties) and next just start.

Overview table 4 – Critical knowledge and data gaps

Gaps	Fundamental processes	Knowledge transfer	Guidance in practice
Assessing structural properties and strength characteristics of levees/	X	X	X
Dealing with uncertainties	X	X	X
Levee Information Management			X
Levee Risk Assessment		X	X
Resilience of levees	X		
Impact of wetting/drying cycles	X	X	X
Levee behaviour during flood		X	X
Interaction of failure mechanisms	X		
Performance of transitions	X	X	X
Detections of and dealing with anomalies			X
Realizing added value of levee monitoring (from smart levees to smart use of levees)		X	X
Breach initiation/growth retarding measures	X	X	X
Overtopping resistance/resilience	X	X	X
Performance/erodibility testing of riprap, grass, woody vegetation, road presence etc	X		
Vegetation cover management guidance		X	X
Effect of vegetated foreshores	X		
Overtopping/overflowing hydraulic loading conditions	X		
Burrowing animal activity		X	X
Emergency measures		X	X

15 Appendix A – Levee inventory Questionnaire

The following Questionnaire was used in 2016 to gather some initial data to be included in this report:

1. (*) Country

2. (*) Name

3. Organisation
   a. Function

4. (*) Contact Information :
   a. (*) mail
   b. phone
   c. post

5. Flood defences, physical environment and hazard
   a. What types of flood defences do you have in your country:
      i. How many levees do you have (in km)
      ii. How many flood walls do you have (in km)
      iii. How many hydraulic structures do you have (in numbers)
      iv. Remarks.
   b. What % of your flood defences (of each type) is linked to the following physical environment / flood threat:
      i. Sea
      ii. Estuary
      iii. Lake
      iv. River
      v. Torrent
   c. What would be a typical flood defence height in your country (please give min, max, medium if possible)
   d. Do you have one or more maps and/or GIS-files showing the flood defences position? If possible please upload it here
   e. What % of your flood defences represent, if they break:
      i. No hazard
      ii. Material hazard only
      iii. Some life hazard
      iv. Large scale life hazard/economic hazard (say > 100 people/over 100 million)
      v. Explanatory remarks (if you had to adapt the hazard categories to what is commonly used in your country)
   f. Levee-related costs:
      i. What would be a typical construction and/or rehabilitation cost for 1 km of levee in your country
      ii. What would be the typical maintenance and management cost for 1 km of levee in your country (including inspections and minor repairs)?
      iii. Other information you wish to add (for example on other flood defence types?)
   g. In our report we wish to give an impression of the importance of levees in terms of protected value. Could you give a rough indication of the (levee-)protected population size and economic value in your country?
   h. Explanatory remarks you wish to add (for example levee types that are not included in your answers because they are too small/numerous/cumbersome to elaborate upon, or remarks you wish to make about natural flood protection features like dunes).

6. Safety standards:
   a. What are typical (levels of) safety requirements for the hazard categories mentioned in the previous question [5e]?
      i. No hazard
      ii. Material hazard only
      iii. Some life hazard
      iv. Large scale life hazard/economic hazard (definitions of this category may differ across countries; as rough indication, large scale may mean at least 100 victims or 100 million Euro damage)

b. Safety requirement definitions may differ across countries. Please explain how the above safety requirements are defined (for example maximum allowable values of risk level, flood probability, water level a levee can just withstand, water level a levee can just withstand, …)
c. To what type of Limit State do these requirements refer (if you are familiar with Box 5.11 of the International Levee Handbook, please use the terms Protection Level or Safety Level or Danger Level; if easier you can also use the 'Some Damage', 'Serious Damage', and 'Ultimate' Limit State).
d. Are these safety standards included in, or referred to in law? How?
   i. Included in law
   ii. referred to in law, included in underlying legislation
   iii. Not included in formal legislation
   iv. Please give further specifications/explanations if appropriate.
e. Further to subquestion "c". Are legal requirements for dams and levees roughly similar? If not, please point out the main differences between (i) levees, (ii) flood control dams and (iii) regular dams, considering the aspects of question 5?
f. Do you have maps with safety requirements you can upload?
g. Explanatory remarks you may wish to add…

7. Safety assessment / inspection status:
   a. Most countries have a system for periodic safety assessment and/or inspection of the flood defences. If such status reports are available, please add this information (sufficient, insufficient, unknown). If possible add a map with this information
      - Sufficient safety (%)
      - Insufficient safety (%)
      - Unknown safety (%)
   b. Is there coordinated operation and/or crisis management of upstream dams and downstream levees in the case of immediate flood threat?
   c. Did you have any recent (near-)failures of levees or other flood defences in recent years/decades for large scale hazard? (Y/N)
   d. How often do these (near-)failures roughly occur?
      - >1/year
      - 1/year
      - 1/10 years
      - 1/50 years
      - 1/100 years
      - <1/100 years
   e. In which type of environment?
      - Sea
      - Estuary
      - Lake
      - River
      - Torrent
   f. What are the most common failure mechanisms for these incidents?
      - Overtopping/overflowing
      - Internal erosion
      - Geotechnical instability
      - Other (May include revetment failure, non-closure or structural failure of hydraulic structures, failure at (hard-soft-)transitions, etc.)
   g. Do you have any well-described events that are suitable for case studies? (Y/N)
   i. If YES, please give a brief description and upload relevant web links and document
   h. Are there reports regarding lessons learnt from these (near-)failures.
      i. If yes, could you provide some weblinks or report;

ii. and have the conclusions from these reports have had follow-up in actual actions later?
- No preventative measures proposed
- Preventative measures proposed
- Preventative measures proposed and implemented

i. Did you have any recent (near-)failures of levees or other flood defences in recent years/decades for some life hazard? (Y/N)
    i. Same sub-questions as under item d-h above

j. Did you have any recent (near-)failures of levees or other flood defences in recent years/decades for material hazard? (Y/N)

i. Same sub-questions as under item d-h above

k. Did you have any recent (near-)failures of levees or other flood defences in recent years/decades for no hazard? (Y/N)
    i. Same sub-questions as under item d-h above

8. Management information:
    a. indicate the organization(s) or type of organizations that manage the flood defences. If management is distributed over different organizations, indicate which organization manages which fraction of the levees.
    b. From a management viewpoint, and from a viewpoint of roles and responsibilities (i.e. governance), are there any differences between (i) levees, (ii) flood control dams and (iii) other types of dams worth mentioning, including the way these roles and responsibilities are referred to in law.

9. Dams, levees and the EU Floods Directive (EUFD)
    a. What aspects of dams and levees are included in the products (Preliminary Risk Assessment, Risk Maps and Flood Risk Management Plans) required by the EU Floods Directive (EUFD)?
    b. Are dams and levees similarly dealt with under your countries EUFD-implementation or differently (and in which respects).
    c. Are there any important dam- or levee-related aspects (related to their management, their flood risk, combined risk assessment / management of upstream dams and downstream levees, etc.) the national implementation of EUFD do not consider?
    d. Remarks, lessons and or documents you want to share

10. Dam and levee registers.
    a. Does your country have central dam and/or levee registers?
        - Yes Dams and levees
        - Yes Dams only
        - Yes Levees Only
        - No
    b. If so, what information is included?
        - Profile
        - Safety regulation
        - Maintenance
        - Cross section
        - Other
    c. Who has access to the data?
        - Public information
        - State control authorities
        - Dam and levee management organizations
        - Local authorities
        - other

11. Levees and ICOLD Bulletins
    a. What is your view on the applicability of ICOLD Bulletins/publications to levees and flood defences in your country?
        - Not helpful (yet)
        - Educational but not applicable
        - Some are applicable with adaptation
        - Some are directly applicable
        - Very helpful and applicable
    b. Is the previous answer your personal point of view or do you represent a group of people
    c. Any specific remarks?

12. Other guidance
    a. Apart form ICOLD bulletins and the International Levee Handbook, is there some other type of guidance available in your country?
    b. Can you list the main guidance documents with possibly weblinks?

13. Knowledge gaps:
    a. What levee- and flood-defence related issues and knowledge gaps are critical (to guarantee safety, and the integrity of the structure)?

14. Other remarks:
    ……………

16 APPENDIX B - Report Chapter Template; suggested contents

This chapter contains a template for each of the Cuntry chapters, as well as (in italics) some suggestions for their contents.

X.1 Facts and figures on levees and flood defences

This section is meant to answer questions like:

- *how many levees and other flood defences do you have (km's / nr's)*
  - *other flood defences may be moveable flood walls, storm-surge-barriers and also ordinary gates and sluices (the latter may be so numerous it may be too difficult to quantify them)*
- *what are typical dimensions and other properties (materials, layering, revetment, ..) for (different types of) levee in your country*
- *what is the geographical context: what are typical environments / flood types (% urban/rural levees, % river, estuary or coastal levees)*

You may add a few photographs, but please make sure the file size will not increase more than 1MB.

X.2 Protected value, safety standards and flood risk

This section is meant to give an indication of the following:

- *What is (by and large) the protected value that could flood without levees and flood defences. Both in terms of life and economic value (preferably the assets, otherwise a fraction of the Gross Domectic Product)*
- *Do your levees and structures have a safety standard, and if so what does it refer to and what value has it got*
- *What is the actual protection level of your levees etc. (or what % does or does not satisfy the safety standards)*
- *Coming to the first issue: what is the residual risk (related to flooding despite the levees etc.), and how large is it compared to protected value (the ratio is in fact a measure of the actual protection level)*

X.3 Recent (near-)failures of levees

This section is meant to give a brief description of (near-)failures of levees/structures, and their causes and failure modes. Detailed information is not required, but we wish this section to serve as a portal to this detailed information.
Again, you may add a few photographs, but please make sure the file size will not increase more than 1MB.

X.4 Legislation and governance

Please give a short description about the main legislation related to levees and flood defences.

Please also indicate whether (i) this legislation is similar or even identical to the legislation used for dams (please check the Dam Legislation Report from the ICOLD European Club; levees are mentioned at least for ES, FI, FR and NL) and whether (ii) this legislation is a translation of the EU Floods Directive. The latter is interesting, because it allows to get an indication to what extent the Floods Directive has resulted in a common legal framework throughout Europe.
Besides this, it is also important to describe the key players with respect to Levees and Flood Risk Management and how they interact, i.e. the governance with respect to all life cycle phases of Levees and Flood Defences. Not only to describe the governance, but also to make clear how easy/difficult it is to get relevant information.

X.5 Guidelines and good practices

Please mention what guidelines and good practice documents you use for design, safety assessment and maintenance of levees/flood defences; please give references/weblinks to some key documents. Please also mention what parts of ICOLD-Bulletins and/or the International Levee handbook ILH are used in your country for the above.

X.6 Common practices during Levee Life Cycle

This section is meant to briefly share some common practices related to various life cycle phases of Levees & structures:

- *Design practice and cost of reinforcement (per km or per object)*
- *Inspection of levees*
- *Maintenance and safety assessment*
- *Flood event management*
- *…*

X.7 Summary of key facts

This section is meant to summarise some key facts and figures in just a few words, for easy comparison amongst countries, and to facilitate writing the summary and conclusions:

- *Km of levees, no. of structures*
- *% along river, estuary, sea, lake*
- *Protected value, safety standard, actual protection level or flood risk*
- *Recent (near-)failures*
- *Key facts governance (which key players) and legislation*
- *Types of guidelines used*

X.8 References (per country)

Please support the Country-specific facts of the previous sections by references and weblinks as much as possible, so that information remains traceable and easy to update.

Comité Français des **Barrages** *et* **Réservoirs**

Le comité français des **barrages** *et* **réservoirs** *(CFBR), anciennement comité français des grands barrages (CFGB), est une association scientifique et technique créée en 1926. Il constitue la branche française de la commission internationale des grands barrages (CIGB).*

L'association a pour objet de provoquer des progrès dans la **conception**, *la* **construction**, *l'***entretien** *et les* **méthodes d'exploitation** *des barrages, des réservoirs et des digues, en rassemblant la documentation, en étudiant les questions qui s'y rapportent, notamment d'ordre technique, économique, sociétal et écologique, et en contribuant à la diffusion des connaissances.*

A ce jour, le CFBR comprend 546 membres, représentants des **administrations**, *des* **maîtres d'ouvrages**, *des* **ingénieurs-conseils**, *des* **entrepreneurs**, *des* **experts individuels**, *des* **chercheurs** *et des* **enseignants**, *tous désignés en raison de leur compétence.*

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