# Flood protection based on the concept of differentiated design levels in Hungary

**Örs Antal[1] and Anita Mária Süveggyártó[2]**
Department of Flood Protection, General Directorate of Water Management, Budapest, 1012, Hungary[1]
E-mail: antal.ors@ovf.hu

Department of Flood Protection, General Directorate of Water Management, Budapest, 1012, Hungary[2]
E-mail: suveggyarto.anita@ovf.hu

**ABSTRACT**

Hungary is located in Central Europe, within the territory of the Carpathian Basin. Due to its hydrographic and basin-like, lowland characteristics, the country is highly exposed to fluvial flood phenomena.

Extreme meteorological conditions and the continuous deterioration of the water-carrying capacity of riverbeds necessitate the constant increase of design flood levels and the elevation of dikes. However, it is evident that continuously raising the height of dikes is an irrational and unsustainable solution due to infrastructural constraints and financial considerations.

With regard to this paradigm, the concept of differentiated flood protection was elaborated. This approach considers not only hydrological factors when determining the design level of dikes but also takes into account quantifiable factors related to the protected side and flood control response possibilities.

The consequence of risk-based, necessary development of dikes is the efficient use of resources, focusing on the necessary and sufficient reduction of risks, avoiding unjustified developments based on risk, and formulating a strategy that is feasible in medium and long term and whose effectiveness can be verified through risk calculations.

The current design regulations can be considered as rigid, determining the construction level of flood protection dikes based on determined height levels and safety levels derived from hydrological statistics. The developed differentiated methodology and concept aim to change this overly rigid and unviable practice. In summary, this new approach based on the principle of differentiation allows financial resources allocated for dike development to be directed to sections where technical considerations and risk assessments indicate a genuine need. By reallocating these funds, we can achieve a reduction in risk for areas that are truly high risk.

This paper presents the methodological background and practical results of this principle, highlighting the technical aspects applied during the differentiation process.

**KEYWORDS:** design level, differentiated method, flood risk mitigation, risk analysis, freeboard, dike

## 1 INTRODUCTION

Flood protection in Hungary is primarily ensured by approximately 4.400 km of flood protection dikes across the country. The current regulation of design framework for the construction of flood protection lines is overly rigid. It is based on hydrological statistical methods that no longer adequately address several factors of growing importance, such as the impacts of climate change, the dynamic evolution of risk levels or the constraints imposed by cross-river structures (e.g. utilities, bridges, etc.). In the existing design system, the most critical issue is that, as a result of both natural processes and human interventions, design flood levels have increased to such an extent compared to earlier levels that upgrading the flood protection system to the prescribed standard is neither economically nor technically feasible within a foreseeable timeframe.

A potential solution is the introduction of flood protection based on differentiated design levels, which emerged as a national flood risk management alternative during the preparation of the Hungarian Flood Risk Management Plan. In addition, this approach offers an effective means of optimizing the use of available financial development resources, thereby enabling faster and more sustainable improvements in flood safety. The development of the hydrological, mathematical, and risk assessment foundations of the differentiated methodology took place over several years as part of a complex planning process. Its development is closely linked to the implementation of the EU Floods Directive; during the first review cycle of Hungary's Flood Risk Management Plans, the methodological development of differentiation was identified as a priority measure. The work aimed at defining the principles and levels of differentiated flood protection was being carried out under the coordination of the General Directorate of Water Management, which organisation is responsible for the operational management of water resources in Hungary. This comprehensive task was implemented by experts of the Hungarian water management planning company, called VIZITERV Environ Non-profit Ltd., with the involvement of the territorial water management directorates.

The new concept in Hungary treats construction levels in a differentiated manner depending on the design flood levels. The main flood protection lines must be constructed to an optimal level everywhere, ensuring the prescribed height safety (freeboard), which is determined solely based on technical criteria.

This manuscript presents the developed methodological aspects of this approach and discusses the concept within the context of international practice.

## 2 FLOOD PROTECTION SYSTEM OF HUNGARY: DESIGN PRINCIPLES AND ORIGINS OF FLOOD DEFENCE LINES

### 2.1 Characteristics of flood hazard in Hungary (in international comparison)

The flood hazard in Hungary is fundamentally determined by the country's hydrological and topographical conditions. Hungary is located in the Carpathian Basin, which is the largest intermontane basin in Europe; consequently, the discharges of its watercourses are predominantly influenced by the surrounding mountain ranges forming the upstream catchment areas. In addition, the high level of flood and inland excess water hazard is further reinforced by the fact that approximately 68 % of the country's territory lies below 200 m above sea level. Depending on precipitation conditions, about 95 % of the annual discharge of Hungarian rivers originates outside the national borders. This flow rate enters the country through a transit river network with an uneven spatial distribution, concentrated towards the central lowland areas, and subsequently leaves Hungary in a southward direction. Altogether, 22 rivers flow through the territory of Hungary, with a total length of approximately 2.800 km *(Antal, 2017)*, which is considered significant relative to the size of the country.

Flood waves and flood events along Hungarian rivers are primarily generated and controlled by precipitation amounts measured within the upstream catchments, as well as by the magnitude and rate of snowmelt associated with rising temperatures. Due to the characteristic ecosystems of lowland areas, favourable loess-based soils for agricultural production, and a specific vegetation structure with relatively limited forest cover, conditions are particularly conducive to the formation of inland excess water and floods. Approximately 30 % of Hungary's agricultural land is affected by flood hazard *(Tasnádi, 2020).* These findings are further supported by studies examining the impacts of climate change on the vulnerability and economic performance of European countries. In the case of Hungary, research has demonstrated that large river floods, along with impacts on agricultural production and broader hydrological risks – including changes in precipitation patterns – represent a significant economic exposure both at present and in the future *(Boitier et al., 2024)*.

Based on the above mentioned factors, it can be concluded that the flood hazard in Hungary is primarily governed by fluvial flooding. These phenomena are caused by large rivers and flood waves originating from upstream catchments located outside the country. Owing to the country's topography and the dominance of a temperate continental climate, local precipitation events and flash floods are of lesser importance in terms of overall flood hazard and risk.

The flood protection system in Hungary has been developed in accordance with these characteristics. As a result, the backbone of the flood protection system consists mainly of long, continuous embankment sections, behind which substantial assets are concentrated. Defence capacities, intervention capabilities, as well as strategic and technical design principles and developments, are therefore largely aligned with these linear flood protection structures. The severe Central European flood events of 2024 further confirmed that, compared to neighbouring countries, Hungary generally benefits from longer lead times, which – beyond civil protection tasks – allow for a strong focus on the proper operation and application of flood protection infrastructure, as well as on the high level of technical expertise required for flood control operations.

### 2.2 Methodology of design flood level determination in Hungary: an international comparison

The fundamental design unit of Hungary's flood protection system is the design flood level calculated using a standardized hydrological-hydraulic statistical methodology. Based on the analysis of discharge time series observed along a given river, the corresponding water level is determined for a flood wave with a specified return period (e.g. 100–1.000 years). Earlier practice defined the design level on the basis of the historically observed maximum water levels, however, as this approach did not account for morphological changes of the river channel, human interventions affecting the channel, or land-use changes, the derivation of water levels from discharge statistics proved to be a more appropriate methodology. Consequently, since the 1970s, the design flood level determining the crest elevation of flood defence lines has been uniformly defined as the statistically derived value of the annual maximum ice-free floods corresponding to a given probability of occurrence (return period). The impacts of climate change, together with successional and sedimentation processes taking place within floodplains, have demonstrated scenarios in which the repeatedly revised calculated design flood levels remain economically viable only if appropriate interventions are implemented within the floodplains and riverbeds. For this reason, Hungarian water management bodies prepared Floodplain Management Plans for the country's major watercourses in 2015 *(General overview of floodplain management plans, 2015).*

The above mentioned considerations demonstrate that, throughout the country's history, the vertical upgrading of the flood protection line system has consistently been a fundamental element of Hungary's flood protection strategy. This strategy has evolved over time in response to changing water management demands and climate change scenarios, while its design basis in Hungarian practice has remained the design flood level corresponding to the 100-year return period flood event ($Q_{100}$).

Directive 2007/60/EC of the European Parliament and of the Council (the EU Floods Directive) prescribes only one specific return period ($\geq Q_{100}$) as direct design parameters for the Member States, rather defines probability-based categories. This provides Member States with the flexibility to develop their flood hazard and flood risk management plans, as well as their design and dimensioning criteria, in accordance with scenarios relevant to their own territories. As a result, regional heterogeneities and economic considerations can be more effectively taken into account. The latter plays a particularly important role in Hungary in the methodology applied for the differentiation of flood defence design levels.

The "FLOPROS" database developed by *Scussolini et al. (2016)* analyses national and regional differences in flood return periods associated with flood protection measures across Europe and worldwide. This provides a solid basis for comparing the degree of flexibility applied in neighbouring countries' design standards, as well as for examining how climate change and other influencing factors are incorporated into design calculations. Based on FLOPROS data, the characteristic return periods used as typical design bases in several countries have been compiled (Table 1):

Table 1 Design flood return periods applies in different countries *(Scussolini et al., 2016)*

| **Country** | **Typical Design Basis (Return Period)** | **Other scenarios** |
|---|---|---|
| Hungary | $Q_{100}$ | Additional freeboard above the design flood level depending on the built-up intensity (1.0-1.5 metres) |
| Germany | $Q_{100}$ | Higher standards ($Q_{200}$-$Q_{500}$) for critical areas depending on regional regulation |
| Austria | $Q_{100}$ | Additional freeboard depending on the importance of the protected area (typically 0.5–1.0 metres) |
| Switzerland | $Q_{30}$-$Q_{200}$ | Differentiated per land use, $Q_{30}$ in rural areas |
| Slovak Republic | $Q_{100}$ | Additional freeboard |
| France | $Q_{100}$ | |
| Italy | $Q_{100}$ | $Q_{200}$-$Q_{500}$ for densely populated areas, critical infrastructures and high-value assets |
| United Kingdom | $Q_{10}$- $Q_{1000}$ | $Q_{200}$-$Q_{1000}$ in urban areas. Tidal flooding also considered |
| Netherlands (Jorissen et al., 2016) | $Q_{250}$–$Q_{10000}$ | Highest protection standards based on dike ring areas |
| Poland | $Q_{100}$-$Q_{500}$ | |
| Czech Republic | $Q_{20}$-$Q_{200}$ | |
| Canada | $Q_{100}$-$Q_{700}$ | Mainly $Q_{200}$. Provincial regulation, values vary by regions and municipalities. |
| United States | $Q_{100}$ | $Q_{200}$-$Q_{500}$ for major cities and critical infrastructure |

For the countries listed, the regulation of the design reference levels is typically established at the national level (with the exception of Canada, where regulation is defined at the provincial level). In the practice of several countries, however, differentiation at the local (municipal) level is also applied, primarily driven by the risk characteristics of major urban areas. In Hungary, such local-level differentiation is prescribed specifically with respect to the required freeboard above the design flood level.

The data presented in the table clearly indicate that in most European countries, as well as in Canada and the United States, return periods of approximately 100–200 years are predominantly adopted as design bases. However, beyond coastal flooding considerations, local flood protection levels may be significantly influenced by the spatial distribution and magnitude of flood risk. Consequently, the observed differences do not arise from hydrological conditions, but rather from risk-related considerations, typically associated with densely populated areas or the presence of critical infrastructure.

### 2.3 Technical and economic performance of developments based on the current design standards

To provide budgetary support for the differentiated methodology underpinning a sustainable development strategy, the height-deficient sections of flood protection lines and the costs required to upgrade them to comply with current standards can be straightforwardly presented based on the national registry of the General Directorate of Water Management *(Table 2).*

Table 2 Length of state-managed flood protection lines with height deficiencies relative to current standards *(Off. register, 2025)*

| | |
|---|---|
| **Total length of flood protection lines:** | **4.414 km** |
| Earthen embankments: | 4.099 km |
| High banks: | 219 km |
| Flood protection walls: | 22 km |
| Other (railway, road, wall): | 74 km |
| **Sections with height deficiency:** | **3.055 km** |
| **Degree of height deficiency:** | **69 %** |

Based on the above data, it can be stated that currently only approximately 30 % of the primary flood protection lines in Hungary comply with the applied design standards. In addition, around 250 km of flood protection sections under municipal management must also be considered, where this proportion is even lower.

According to embankment development projects implemented during the 2014–2020 European Union funding period *(Government Resolution 1084/2014),* the total cost of upgrading 1 kilometre of flood embankment - including land acquisition and other project-related costs - amounted to approximately HUF 600 million gross (≈1.6 million EUR). Taking into account changes in the construction producer price index *(Hungarian Central Statistical Office, 2025),* this corresponds to an estimated compound price increase of approximately +75 % by the end of 2025, meaning that the current unit cost now exceeds 1 billion HUF per kilometre (≈ 2.6 million EUR).

This clearly demonstrates that achieving full compliance with the current design standards does not represent a rational solution for either the state or local governments, even over several decades, particularly given that ongoing morphological changes and the increasing extremes associated with climate change are expected to further raise design flood levels in the future.

All of these factors necessitate a revision of the current rigid regulatory framework in Hungary and support the introduction of a differentiated approach. Cost rationalisation is further enhanced by the fact that differentiation enables the integration of the risk reduction effects of existing flood retention reservoirs, as well as the quantification of flood control and emergency response capacities.

## 3 PRINCIPLES AND CALCULATION METHODOLOGY FOR DIFFERENTIATED FLOOD PROTECTION DESIGN LEVELS

### 3.1 Principle of differentiation of flood protection design levels

Based on the discussion above, it can be concluded that the nationally prescribed design requirement in Hungary – based on a 100-year return period flood event and a uniform freeboard – constitutes an excessively rigid system that is neither technically nor economically sustainable. Taking international practice into account, this has prompted efforts to establish the foundations of a more flexible design regulation as an addition to the current provisions. As part of this process, a new calculation methodology has been developed which, in addition to hydrological considerations, also forward-lookingly incorporates territorial characteristics, risk levels and defendability. In the long term, this represents a section-by-section differentiated approach that facilitates the efficient and targeted use of financial resources allocated to flood protection.

In Hungarian professional practice, the strategic approach to differentiated design levels is defined by water management experts as follows: *"The fundamental objective of differentiated development – based on the risk values on the protected side of flood defence embankments – is to establish a sustainable flood protection system that, in addition to ensuring flood safety, demonstrates clear social acceptance and effectiveness" (Dobó, 2023).*

According to the nationally developed calculation methodology, the differentiated level represents an optimal, defensible protection level, which incorporates technical freeboard, the effects of flood retention storage and linear flood control measures. Furthermore, in parallel, compared to the examined parameters it identifies the optimal level of embankment development at which the invested costs remain rational relative to the residual risk values achieved through the intervention.

The minimum development level was defined as [current design flood level-60 cm]. This threshold was introduced to avoid significant inequalities in flood defence capacities at the national scale. Accordingly, all flood defence lines are required to be upgraded at least to the level of the current design flood level minus 60 cm. Any protection level above this threshold is determined on a risk basis within the framework of differentiated flood protection, in accordance with the EU Floods Directive.

Under the differentiated approach, the extent of development for a given flood protection cross-section is determined as the sum of the differentiated level – defined relative to the currently prescribed design flood level – and the required freeboard, as outlined below:

**Differentiated design level = Differentiated level + freeboard**

### 3.2 Methodology for calculating differentiated levels

The differentiated level represents a "maximum defensible level," corresponding to a flood peak at which the given floodplain compartment can still be effectively protected.

The basis of differentiation is the flood risk calculated for the protected floodplain compartment as a whole and the relevance of the required investments. The assessment accounts for the risk-reducing effects of existing flood retention reservoirs and linear flood defence operations. According to the methodology, embankment upgrades to the differentiated levels are justified where the combined effects of retention and operational flood defence do not achieve the defined optimal level, or where the cost of embankment development to the current design levels is disproportionate relative to the risk reduction attained. All of these relationships are summarised schematically in the figure below *(Figure 1)*.

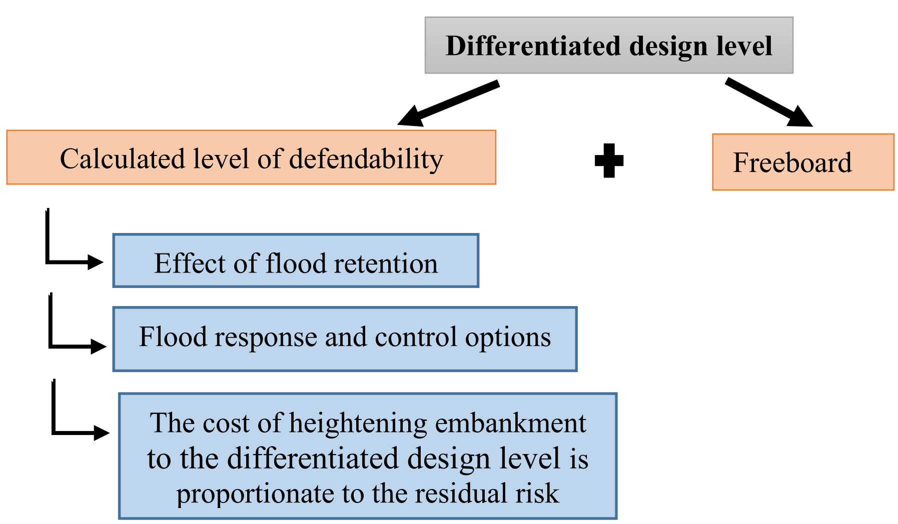


Figure 1: Methodology for calculating the differentiated design level *(edited by the authors)*

In Hungary, the methodological basis of flood risk calculation is provided by the risk assessment framework developed within the Flood Risk Management Planning (FRMP) project, prepared as part of the implementation of the EU Floods Directive. The differentiated calculation method does not modify the fundamental FRMP risk calculation formula, however, it treats protected floodplain compartments separately and assigns different acceptable risk levels to them. The spatial calculation of flood risk within the FRMP is based on flood hazard (inundation) maps produced through hydrodynamic modelling. Risk is calculated for each spatial unit of the exposed area using a raster resolution of 20×20 m. Based on the inundation simulations, the expected damages associated with individual flood events are determined and weighted by the probability of occurrence of the respective inundation events. The resulting risk is expressed as the expected annual average damage.

According to the risk assessment, the determination of acceptable risk levels was based on the ALARP (As Low As Reasonably Practicable) risk tolerance principle, applying evaluations grounded in cost-benefit analysis and affordability considerations. An optimal level of risk can be considered achieved when the risk assessment confirms that, in accordance with the ALARP principle, no residual risk remains within the unacceptable region, and that, as a result of risk reduction measures, the remaining risk is reduced to an acceptable level *(Ganszky, 2023)*.

### 3.3 Calculation of freeboard

Under the current design regulations, a uniform freeboard of 1.0 m is prescribed for all rivers in the case of primary flood defence lines. Higher values – typically between 1.2 and 1.5 m – are required for major urban areas and for flood protection lines forming state borders. The application of lower freeboard values is permitted by regulation only in a limited number of cases, mainly for embankments along channels affecting only agricultural areas. This simplified, largely analogue calculation approach therefore fails to account for several factors that could allow for the determination of more realistic freeboard values based on defendability and technical parameters. In the case of differentiated design levels, the calculation methodology weights the following technical factors when determining the required freeboard for a given flood protection section:

1. Average embankment height (**$\bar{H}$**)

| Criterion (m) | Freeboard (m) |
|---|---|
| $\bar{H} < 2$ | 0.5 |
| $2 \leq \bar{H} < 5$ | 1 |
| $5 \leq \bar{H}$ | 1.2 |

2. Extent of available lead time **(D)**

| Criterion (day) | Freeboard (m) |
|---|---|
| $3 \leq D$ | 0.5 |
| $1 \leq D < 3$ | 1 |
| $D < 1$ | 1.2 |

3. Total floodplain width **(W)**

| Criterion (m) | Freeboard (m) |
|---|---|
| $W < 200$ | 0.5 |
| $200 \leq W < 1000$ | 1 |
| $1000 < W$ | 1.2 |

4. Distance from river mouth (**D**)

| Criterion (km) | Freeboard (m) |
|---|---|
| 15 ≤ D | 0.5 |
| 5 ≤ D < 15 | 1 |
| D < 5 km | 1.2 |

5. Type of flood defence structure

| Criterion | Freeboard (m) |
|---|---|
| wall | 1 |
| earthen embankment | 1.2 |

The value of the freeboard is calculated as a weighted average of the factors listed above, with priority given to embankment height and the structural type of the flood defence.

### 3.4 Social conflicts and their management

One of the primary objectives of differentiation is to allocate proportionally greater development efforts within the differentiated approach to high-risk protected floodplain compartments (and river reaches) than to medium- and low-risk areas, thereby focusing interventions on the most problematic locations. As a consequence, social conflicts may arise. The essence of the methodology is differentiation rather than discrimination. Nevertheless, these issues must be addressed through engagement with local stakeholders. Within a research project, the General Directorate of Water Management examined the management of socially related conflicts, leading to the following key findings *(Revision of flood safety concepts, 2023):*

- the development of a national-scale socio-economic evaluation model is required, including the assessment of risk threshold values based on the economic performance capacity of the economy and the affordability of the population, as well as for productive sectors, considering both the current situation and the differentiated flood protection alternatives;
- for those river sections or protected proteted floodplain compartments that are assigned lower development priority due to limited defence capacities and possibilities, it is essential to ensure the maintenance of flood defence resources and operational capabilities;
- in the case of opposing flood protection lines, the differences resulting from differentiated developments must be addressed through national-level coordination combined with local-level social consultation. For this purpose, focus-group stakeholder forums were organised within the framework of the National Laboratory for Water Science and Water Security, based on designated pilot areas*;*
- and the population and local governments must be adequately informed about the rationale of investments and strategic decisions, as sociological research has shown that they often lack information regarding the challenges faced by water management authorities and the organisation's long-term plans.

## 4 EXPECTED OUTCOMES OF THE METHODOLOGY

### 4.1 Advantages of applying the differentiated methodology

Given that differentiated embankment development seeks an optimal solution, it approaches – though does not fully attain – the flood protection effectiveness of full-scale development, while requiring substantially fewer resources, thereby representing a more sustainable alternative. Quantitatively, this implies that, at the national level, the differentiated approach achieves a lower residual risk at approximately one-third of the cost, meaning that financial resources can be utilised far more efficiently while delivering benefits (risk reduction) of a comparable magnitude. During the first review cycle of the Flood Risk Management Plans, VIZITERV Environ Non-profit Ltd., commissioned by the General Directorate of Water Management, carried out calculations to compare the risk reduction effects of the currently prescribed standards with those of the differentiated alternative. The results of this comparison are presented in the table below.

Table 3 Cost-benefit indicators of the currently applied design level and the differentiated design level *(FRMP, 2021)*

| **Indicator** | **Currently applied design level** | **Differentiated design level** |
|---|---|---|
| Cumulative initial asset risk [thousand HUF/year] | 152 151 470 | 152 151 470 |
| Residual risk [thousand HUF/year] | 50 073 346 | 11 501 516 |
| Residual risk ratio [%] | 33 | 8 |
| Risk reduction [thousand HUF/year] | 96 544 740 | 124 901 984 |
| Risk reduction ratio [%] | 63 | 82 |
| Risk reduction over 30 years [thousand HUF/30 years] | 1 892 276 904 | 2 448 078 887 |
| Investment cost (2022 price level) [thousand HUF] | 866 884 457 | 166 848 141 |
| Benefit-cost ratio | 2,18 | 14,67 |
| Expected annual flood defence cost [thousand HUF] | 618 538 | 680 540 |
| Expected flood defence cost over 30 years [thousand HUF] | 12 123 351 | 13 338 591 |
| Expected total cost [thousand HUF] | 879 007 808 | 180 186 732 |
| Expected benefit [thousand HUF] | 1 892 276 904 | 2 448 078 887 |
| Overall benefit–cost ratio | 2,15 | 13,59 |

Based on the above indicators, it is evident that implementing the differentiated alternative results in substantially greater risk reduction while requiring only a fraction of the investment cost. It should be noted that the values presented in the table above do not include the examination of all protected floodplain areas in Hungary, they only cover areas with high and extremely high risk from the FRMP review. In the current implementation cycle of the Floods Directive, a partial modification of the differentiated levels is underway prior to the legislative process of the new design units.

### 4.2 Priorisation of developments

During the first review cycle of the Flood Risk Management Plans – within which the development of the differentiated alternative was identified as a priority measure – experts selected, based on flood risk calculations, those protected floodplain comaprtments where high and extremely high risk could be identified and the embankment developments should be prioritised from among the 145 protected floodplain compartments designated in Hungary. As part of the development of the differentiated alternative, a phasing proposal was also prepared, which is illustrated in the figure below. It can be clearly observed that the primary development areas are located in the Tisza River basin, particularly along the Middle-Tisza and the Körös regions.

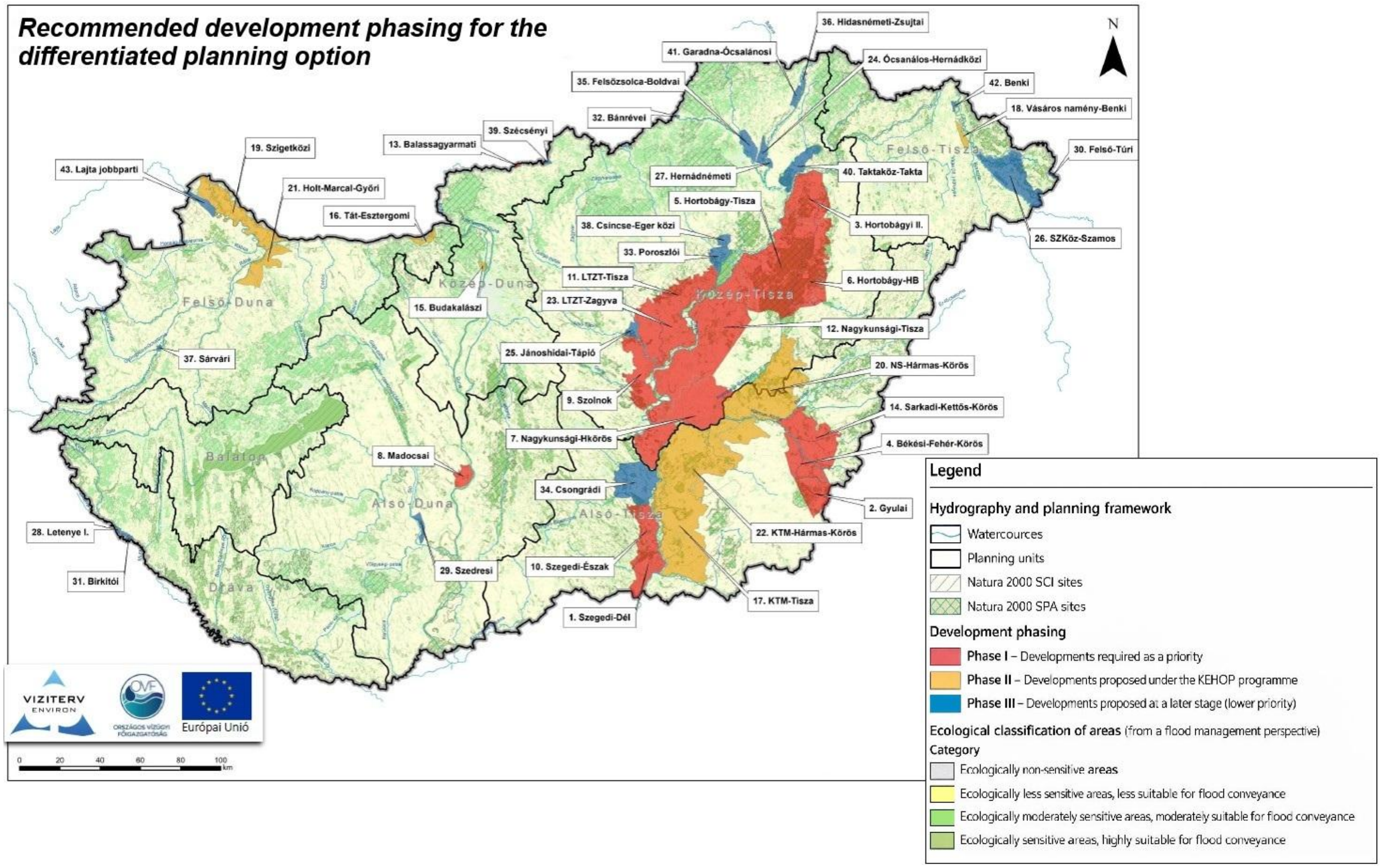


Figure 2: Recommended implementation phasing for the differentiated design option *(FRMP, 2021)*

## 5 CONCLUSIONS

In Hungary, the regulation governing the vertical development of flood protection lines defines the prescribed design levels based on a hydrological statistical approach. By now, it has become evident that this methodology requires further development. This necessity arises partly from economic feasibility considerations, and partly from the need to methodologically incorporate additional factors which – by explicitly addressing defendability – can provide a far more efficient and sustainable alternative in terms of both risk reduction and costs.

Compared to international practice, flood safety standards in Hungary are generally more moderate rather than more stringent, and further easing of these standards would not be appropriate. However, achieving and constructing the prescribed level of full protection would impose a substantial burden on the Hungarian economy or would require an excessively long implementation period, particularly in view of the continuous increase in design flood levels and the exceptionally long extent of flood protection lines by European standards.

The application and implementation of differentiated development levels as a governing design standard can bring the most significant improvements especially in locations where the risk is high or extremely high and the height of flood embankments does not even reach the currently prescribed design flood level. By exploiting this approach – namely, upgrading critically low sections to a defensible level –

critical deficiencies can be eliminated more rapidly, as defendability can be achieved over longer sections at lower cost than full protection. The reduced costs associated with the proposed alternative result from incorporating the risk-reducing effects of flood control operations and flood retention storage, which can be realised at more favourable costs, while embankment upgrades are carried out only to the extent required on a risk basis.

A key methodological element of the differentiated design levels planned to be introduced in the near future is that the prioritisation and extent of proposed developments are determined based on the level of risk on the protected side of the flood protection facilities. This, in turn, necessitates continuous updating through Flood Risk Management Plans in order to adequately capture the dynamic evolution of flood risk. It is also important to note that the sustainability of the design levels underpinning embankment developments can only be ensured through the implementation of floodplain management interventions and construction regulations given the adverse changes occurring on the floodplains of Hungary's typically low-gradient rivers.

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