FLOOD CONTROL MEASURES IN THE LOWER RHINE BASIN

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ABSTRACT

The Lower Rhine basin is situated in the western part of Germany and extends from the city Bonn up to the Dutch border. This region is one of the most populated industrial areas in Germany which consequently leads to immense flood damage potential. Levees are the backbone of the flood protection works. The continuous rehabilitation of these levees, some of which originate from the beginning of the 20th century, is therefore indispensable. A road map which is coordinated by the local government shows the status and the progress of the levee rehabilitation works in the district of Duesseldorf.

The establishment of controllable flood polders as well as the relocation of levees for an increase of flood retention volume and the reduction of the flood levels are additional components of a sustainable flood management. The establishment of flood retention polders in the Lower Rhine region is realized hand in hand and similar to campaigns such as the "Integrated Rhine Programme" (IRP) for the Upper Rhine area.

The paper provides an overview of the major flood protection works at the Lower Rhine and illustrates the challenges by selected case studies for levee works and flood protection polders as well.

1. INTRODUCTION

With a total length of 1249 km, the Rhine crosses four countries and has got the third biggest catchment area in Europe. The course of the Rhine in combination with the different sub basins is shown in Figure 1. The main stream of the Rhine is separated in different sections which are listed in Table 2. The Lower Rhine extends from Rolandswerth, a small district in the south of Bonn, along the cities Cologne and Duesseldorf up to Lobith, which is located directly behind the Dutch- German country border.

Table 1 : The sections of the Rhine (ICPR, 2001)

Section of the Rhine	Stretch	Rhine km	Countries / Länder
High Rhine	Konstanz to Basel	0 - 170	CH, D (BW)
Impounded southern Upper Rhine	Basel to Iffezheim	170 - 334	F, D (BW)
Northern Upper Rhine protected by dikes	Iffezheim to Bingen	334 - 529	F, D (BW,HE, RP)
Middle Rhine	Bingen to Rolandswerth	529 - 642	D (RP, NRW)
Lower Rhine, protected by dikes	Rolandswerth to Lobith	642 - 857	D (NRW), NL
Rhine delta, protected by dikes	Lobith to estuary	857 - 1030	NL

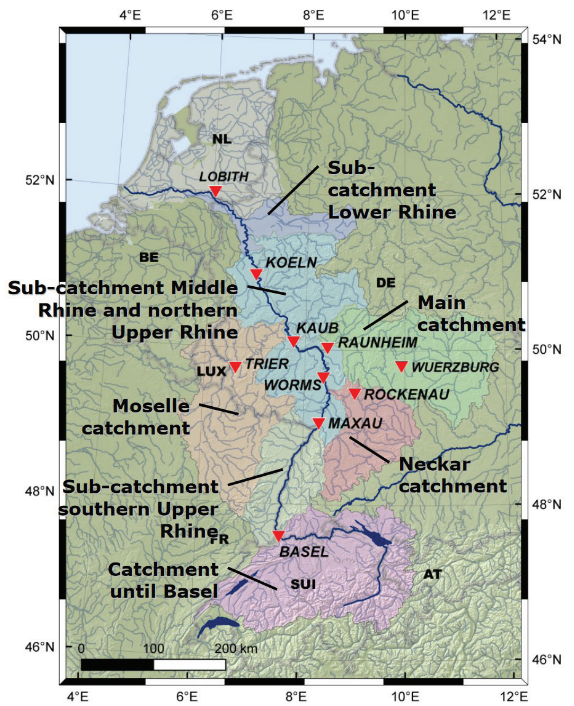

Figure 1 : Subcatchments of the Rhine (ICPR, 2011)

Especially the Lower Rhine area is characterised by an increase of the population density as well as a growing industrialisation which consequently led to the development of one of the highest flood damage potentials in Germany. Therefore, flood protection measures have become more and more important. Meanwhile, several institutions and programs are focusing on the maintenance of human, infrastructural, industrial as well as ecological interests. One example is the transboundary working group "International Commission for the Protection of the Rhine (ICPR)", which started campaigns such as the "Integrated Rhine Programme (IRP)". The aim of the IRP is the reduction of flood levels by the creation and reactivation of flood retention volume hand in hand with improvement of the ecological situation at the Rhine. While the IRP was first focussing on the Upper Rhine area, the project has been extended over the whole Rhine basin. Additional to the reduction of flood levels, the continuous rehabilitation of levees is also indispensable for flood protection at the Lower Rhine. In this context the district council of Duesseldorf established a levee rehabilitation roadmap in order to enforce and follow up the required rehabilitation measures.

The paper reveals the special situation regarding flood risk and flood protection at the Lower Rhine area and provides an overview of the major flood protection works. In this context the specific challenges will be illustrated by the discussion of selected case studies for levee rehabilitation works as well as flood retention polders.

2. FLOOD RISK AND THREATS

2.1 General

For a closer look at the flood risks and threats at the Lower Rhine the history of the Rhine River development has to be taken into consideration. The first river training measures were implemented during the 14th century. Until the 18th century the river length at the Lower Rhine was reduced by approximately 15 km and the river banks were protected by riprap and stabilised (Lange, 2002). During the 16th and 17th century the river training works of the riverbed were continued. Within the 19th century the correction of the Rhine according to the planning of Johann Gottfried Tulla was carried out so that the river length was further reduced by 81 km (LUBW, 2011). In the beginning of the 20th century the focus was set on navigability and hydro power.

In 1993 and 1995 two large floods occurred. Statistically these events represented a 40 year flood in 1993 and a 50 year flood in 1995 (LAWA, 2014). Both flood events caused an economical damage of about 750 Mio. € (Munich Re, 1999).

2.2 Situation – "Ruhrgebiet"

During the industrialisation process in the 19th century, the "Ruhrgebiet", which is located in the northern part of the Lower Rhine area, became the centre of the mining and metal processing industry in Germany. This has led to an immense rise of the population in this region, so that the "Ruhrgebiet" is nowadays the largest urban agglomeration in Germany. As consequence of the intensive mining works enormous soil subsidences occurred during the last centuries. These subsidence processes are still ongoing. In some areas the land subsidence shows values of up to 25 m. Consequently, the levees had to be build higher within the affected area (WDR, 2014). In order to counter this procedure and to prevent a contamination of the ground water by heavy metals resulting from the mining processes, the groundwater level artificially have be kept low so that the mining tunnels will not be flooded. For this purpose a large network of pumping stations is necessary. Figure 2 shows the flooded areas which will occur if the groundwater pumping stations of the "Emscherverband", a water association in the Lower Rhine area, would fail. Similar flooding might also occur in case of a levee failure during a flood event of the Rhine. The electricity supply of the pumping stations might be a critical component in such a case and may suffer from malfunction. In consequence when the groundwater levels will rise the former mining tunnels will be flooded by the Rhine water which will cause permanent contamination. In case of a levee failure at the Lower Rhine, the inundation may reach to the Netherlands (Börger, 2016). For both cases, draining the flooded areas may be economically not possible anymore.

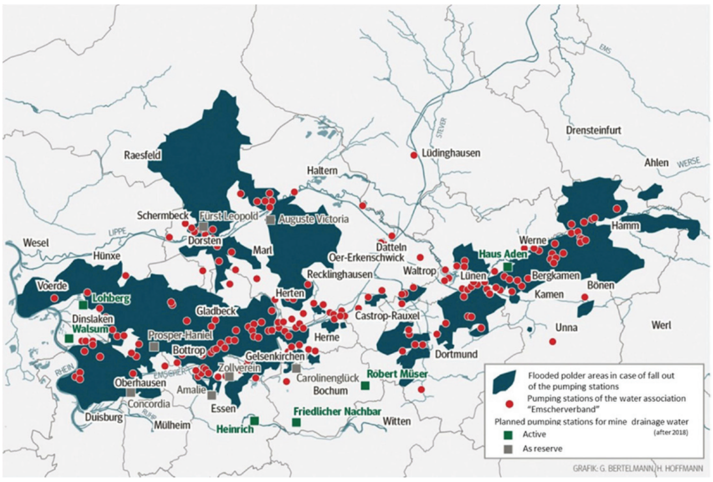

Figure 2 : Pumping stations of the water association "Emschergenossenschaft" and the flooded areas in case of a fall- out of the pumping stations (WAZ, 2019)

2.3 Rhine - Discharges and Design Water Levels

The discharges and the design water levels at the Lower Rhine were defined by the district council Duesseldorf and Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia (MULNV). Since 2004 the design water level "BHQ_{2004}" is implemented. It corresponds to a discharge of 14,700 m³/s at the flow gauging station at Rees, which is located at the northern end of the Lower Rhine basin. Statistically, this discharge complies with a 500 year flood event (MULNV, 2003). The highest measured discharge at Rees (since the start of recording) was measured in 1926 and was 11,700 m³/s (BMU, 2019).

3. SPECIAL CHALLENGES

Summarizing the mentioned aspects, the Lower Rhine area is one of the most populated industrial areas in Germany with huge flood damage potential. Because of the long- time lasting mining procedures in the past, soil subsidence processes occurred and are still ongoing. This is the reason for heightening of the levees in these areas.

Also the groundwater situation which is influenced by the mining processes reflects a long-term challenge also in respect to flood protection works. For all measures the effect on the groundwater conditions have to be assessed duly in order to guarantee the operation of the groundwater wells on a long-term basis.

Some of these large levees were built in the beginning of the 20th century. Therefore, the rehabilitation according to up-to-date regulations such as DIN 19712 as well as the guidelines like DWA-M 507/1+2 and the levee ordinance of the district councils are also challenging since the safety approach changed and more precise requirements were integrated regarding, e. g., pipes, conduits, trees, construction methods or just the hydrological and/or hydraulic conditions. Frequently a demolition of the existing levee and a complete new construction is required. Especially in urban regions, the lack of area and the demands of third- parties are enhancing those projects.

Up-to-date nature and environmental laws and jurisdiction dictate the necessity of avoiding, minimizing and compensating all impacts which are imposed by the project. Unfortunately, especially in industrial areas the levee and its surrounding areas were places where fauna and flora could develop better than in adjacent regions so that frequently the levee area is a nature protected area where red list animals or plants occur. This leads to restriction and with the restrictions imposed by flood danger during the winter months the available construction periods reduce significantly if not compromises are agreed on between all stakeholders.

The infrastructural density on the one hand and the few opportunities for the reactivation of flood retention volume on the other hand lead both to the indispensability of the realisation of the levee rehabilitation in the Lower Rhine area. Due to the extreme damage potential the degree of safety has to be highest as dictated by the corresponding codes and guidelines. Compromises in favour of other uses must not endanger flood safety which is to be considered prior to all other interests and uses of stakeholders.

4. MEASURES

4.1 Flood Risk Management

The objective of a sustainable flood risk management is the reduction of the impact of flood events. Generally, this will be realised by the incorporation of damage prevention, damage protection, the improvement of the preparedness of all affected parties, and the continuous optimisation of these measures after flood events and their consequences. In the context exemplary measures for damage prevention and protection, which have an effect on the situation at the Lower Rhine, are outlined.

4.2 Flood Retentions Structures – IRP

For the realisation of a sustainable flood management, the reactivation of flood retention volume is essential. Therefore, the establishment of controllable flood polders as well as the relocation of levees are effective means for the reduction of the flood levels. The Integrated Rhine Program (IRP) includes the reactivation of flood retention volume and ancient flood plains. The IRP plans to create about 54 Mio. m³ retention volume by the conservation of existing and reactivation of old natural barriers and floodplains as well as by the construction of flood retention reservoirs, relocating levees or dams and by adjusting the operation of weirs (IPCR 2013). In this context Table 2 offers an overview of the measures at the German Rhine.

The effects of the planned measures of the IRP on the flood levels are visualised in Figure 3. The bar charts compare the measures finished in 2010 withthose intended to be finished in 2020 by referencing them to the available retention space of the year 1995. The figure is based on a hydraulic model of the complete Rhine basin with all planned measures. The reduction values are given in cm. The values for a 100-year flood discharge (HQ_{100})are shown on the left side and the values for an extreme flood discharge ($HQ_{Extreme}$[1]) on the right side of the figure.

1 $HQ_{Extreme}$ is an extrapolated flood event which statistically complies with a 1,000 year flood.

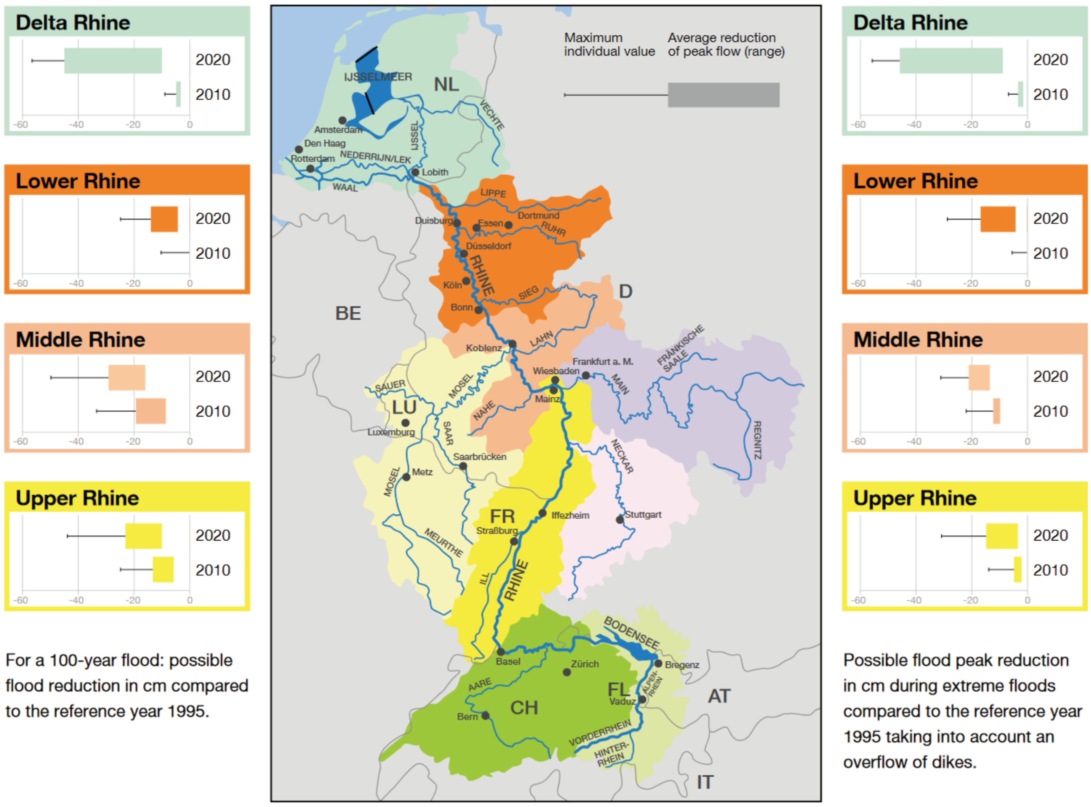

Figure 3 : Flood peak reduction in the different Rhine catchment areas (IPCR, 2013)

4.3 Levee Construction and Rehabilitation Roadmap

In October 2014 the Ministry for Environment, Agriculture, Conservation and Consumer Protection of the State of North Rhine-Westphalia (MULNV), the district council of Duesseldorf, the levee associations and several municipalities agreed on a “levee rehabilitation roadmap” for levees and other flood protection systems. Until the end of 2025 all flood protection facilities at the Lower Rhine from Monheim and Dormagen up to the Dutch border are intended to be realized in line with the current technical regulations. According to this roadmap 40 measures with a length of around 85 km have to be planned and approved before 2025. Furthermore there are 14 projects with a length of about 33 km, which have to be investigated in detail in order to evaluate if there is a need of rehabilitation. In case of the requirement of the rehabilitation, these levee sections will also be added to the rehabilitation projects in the roadmap. The follow-up of the rehabilitation roadmap project will be monitored by the district council of Duesseldorf. (BezReg, 2019)

Figure 4 shows a map of the rehabilitation roadmap, in which the flooded areas for a flood HQ_{100} as well as a flood $HQ_{Extreme}$ are visualised. The colour of the levee sections signalises the necessity of rehabilitation. The green coloured segments were already finished. Rehabilitation measures are needed for the yellow ones. The red coloured sections have to be investigated as a first step. The colour of the textboxes gives an indication of the phase of planning or the implementation periods where red signalises a required investigation project or that the planning is at preliminary design or approval design status. The yellow filling depicts that the project was currently approved. The green colour indicates that the project is in the implementation phase or under construction. The frame colour is a further indicator of the current progress of the single implementation periods. Red means that the current project phase did not start, yellow means that it is in progress and green signalises the completion. The shown map is from November 2017.

5. CASE STUDIES

5.1 General

Six case studies are summarized that are located in the area of the Lower Rhine and that are part of the measures described above. The projects are distinguished thematically in flood retention polders and levee rehabilitation projects. Flood retentions polders are regulated in DIN 19700. Levees are regulated in DIN 19712.

Table 2 : Measures for the creation of retention volume at the Rhine (based on IPCR 2012)

Rhine - km	Section	Country/ State	Location	Kind of measure	Retention volume [Mio. m^3]				
					1995	2005	2014	2020[4]	2020+[5]
174 - 226 234 - 291	Upper Rhine	F	Sidechannel and Slings of the Rhine	flood adapted operating of hydro power plants	45	45	45	45	45
174,6 – 219		D-BW	Weil-Breisach	Subsidence of river banks				2,8[2]	25
224,8		D-BW	Breisach	Retaining weir operation				9,3	9,3
228,4		D-BW	Breisach-Burkheim	Flood retention polder					6,5
243		D-BW	Wyhl/Weisweil	Flood retention polder					7,7
260,5		D-BW	Elzmündung	Flood retention polder					5,3
272		D-BW	Ichenheim-Meißenheim -Ottenheim (IMO)	Flood retention polder					5,8
276		F	Erstein	Flood retention polder		7,8	7,8	7,8	7,8
278,4		D-BW	Altenheim	Flood retention polder	17,6	17,6	17,6	17,6	17,6
290,3		D-BW	Kehl/Straßburg	Retaining weir operation	37[1]	37	37	37	37
302		D-BW	Freistett	Flood retention polder					9
317,4		D-BW	Söllingen/Greffern	Flood retention polder		12	12	12	12
330		F	Moder	Flood retention polder	5,6	5,6	5,6	5,6	5,6
354,9		D-BW	Bellenkopf	Flood retention polder					14
357,5		D-RP	Daxlander Au[3]	Summer polder	5,1	5,1	5,1	5,1	5,1
368		D-RP	Wörth/Jockgrim	Levee relocation			4,2	4,2	4,2
				Flood retention polder			13,8	13,8	13,8
377		D-RP	Hördt	Space reserve					35
381,3		D-BW	Elisabethenwört	Flood retention polder / Levee relocation					11,9
390		D-RP	Mechtersheim	Flood retention polder			3,6	3,6	3,6
390,4		D-BW	Rheinschanzinsel	Flood retention polder				6,2	6,2
392,6		D-RP	Flotzgrün	Flood retention polder		5	5	5	5
409,9		D-RP	Kollerinsel	Flood retention polder		6,1	6,1	6,1	6,1
411,5		D-RP	Waldsee/Altrip/Neuhofen	Levee relocation				1,2	1,2
				Flood retention polder				7,8	7,8
436		D-RP	Petersau-Bannen	Levee relocation				1,4	1,4
439		D-RP	Worms-Mittlerer Busch	Levee relocation			2,1	2,1	2,1
440,2		D-RP	Worms Bürgerweide	Levee relocation		2	2	2	2
467,3		D-RP	Eich	Levee relocation		0,4	0,4	0,4	0,4
468,5		D-RP	Eich	Space reserve					22,6
489,9		D-RP	Bodenheim/Laubenheim	Flood retention polder			6,7	6,7	6,7
517,3		D-RP	Ingelheim	Flood retention polder			4,5	4,5	4,5
668,50	Lower Rhine	D-NRW	Köln-Langel	Flood retention polder			4,5	4,5	4,5
705,50		D-NRW	Worringer Bruch	Flood retention polder				29,5	29,5
707,50		D-NRW	Monheim	Levee relocation		8,0	8,0	8,0	8,0
750,00		D-NRW	Ilvericher Bruch	Flood retention polder					10,0
760,50		D-NRW	Mündelheim	Levee relocation				5,0	5,0
802,00		D-NRW	Orsoy	Levee relocation		10,0	10,0	10,0	10,0
797,50		D-NRW	Orsoy	Flood retention polder				22,0	22,0
818,50		D-NRW	Bislicher Insel[3]	Levee relocation	50,0	50,0	50,0	50,0	50,0
826,00		D-NRW	Bislich-Vahnum	Open					6,5
832,50		D-NRW	Lohrwardt	Levee relocation				13,0	13,0
850,00		D-NRW	Bylerward	Flood retention polder					36,0
Accumulated retention volume of the water level reducing measures at the Lower Rhine by realisation period						***68***	***72,5***	***142***	***194,5***
								ø	***17,7***
Accumulated retention volume of the water level reducing measures at the Rhine by realisation period						***211,6***	***251***	***346,4***	***541,7***
								ø	***12,6***

Comments:

[1] Weir at Kehl: Regular availability of 13 Mio. m³ up to 2002, further 24 Mio. m³ are now availabe in extraordinary cases.

[2] 2,8 Mio. m³ = Section 1 of 4 Sections in total. Additional completion of Section 3 and 4 in 2020.

[3] The "Daxlander Au" and the "Bislicher Insel" have been flood retention areas already before the measures.

[4] The placement of numbers in collumn 2020 is not conterminous with the completion of the measure in some cases. The approval procedures have already started in each case.

[5] 2020+ = after 2020 and in order to the planing up to 2030

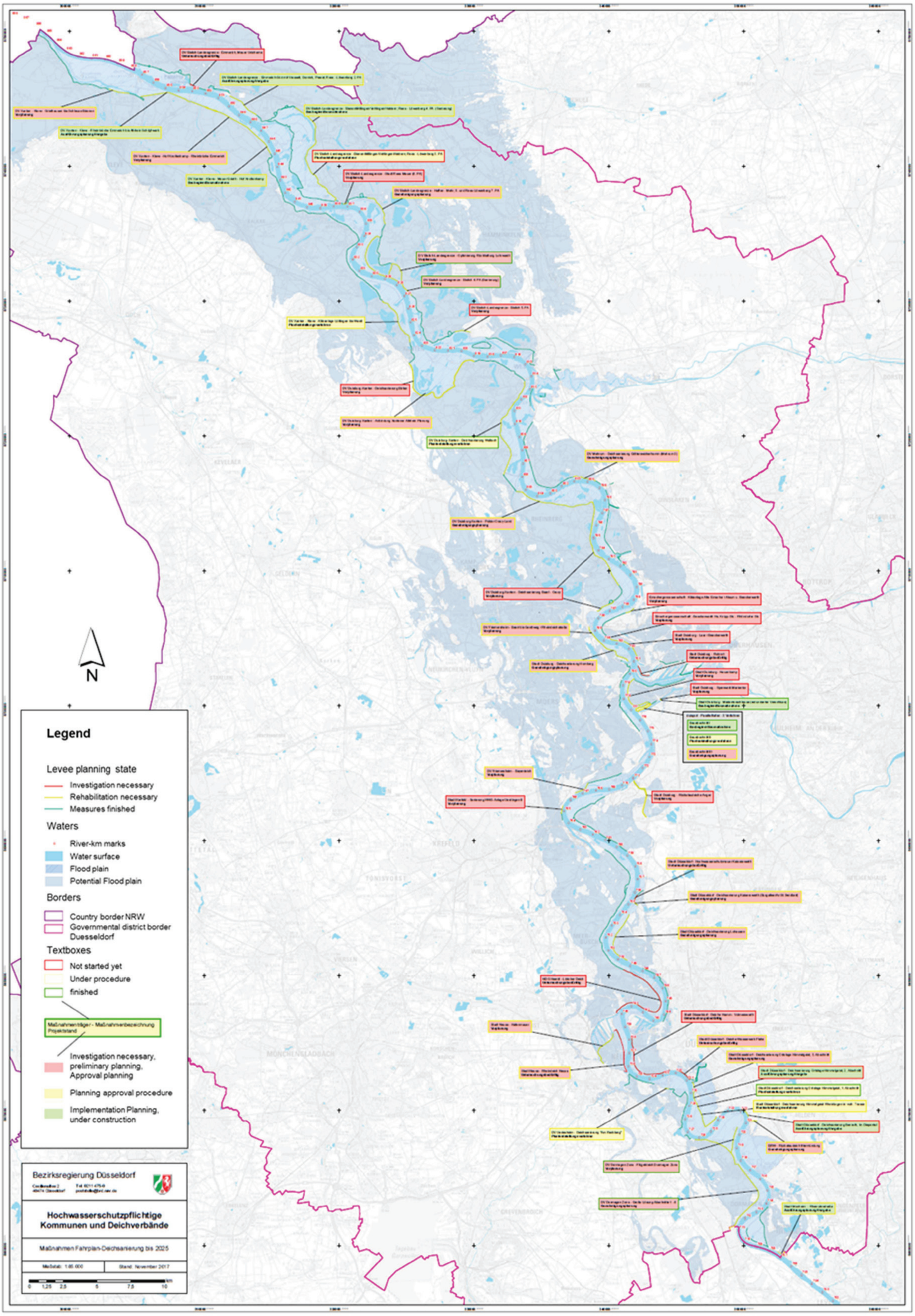

Figure 4 : Levee rehabilitation roadmap of the district council Duesseldorf (BezReg, 2019)

5.2 Flood Retention Polders

5.2.1 *Langel/Cologne*

The flood retention polder in Cologne Langel is located on the right side of the Rhine and provides a retention volume of 4.5 Mio. m³ on an area of 1.6 km². The reservoir area is embraced by two levees. The existing old levee which is located along the Rhine shoreline and shows a length of 2.5 km was rehabilitated by the implementation of a 13 m deep steel sheet pile wall. A new embankment dam was designed as a three-zone embankment dam with a length of 2.0 km and a maximum height of 5.5 m. The height of the embankments is protecting the settlement Langel against a design water level of a 100-year flood event. The water intake structure show a length of 220 m and the inflow weir sill is placed on a height, which is corresponding to a flood event with the statistical probability of occurrence from about 60 years. The maximal inflow while flooding the polder is Q = 90 m³/s. The emptying of the polder is realised by a pumping station with a capacity of 700 l/s and a smaller bypass pipe. The planning and realisation of the project took place from 1997 to 2013 and required construction costs of 14 Mio. €.

5.2.2 *Worringen/Cologne*

On the left side of the Rhine at Rhine- km 707the implementation of theflood retention polder Worringenis planned. The planned polder retention volume amounts to approx. 30 Mio. m³. The planned flood protection height of the polder is corresponding to a water level of a 200-year flood event. The planned flood protection works include three-zone embankment dams and sheet pile wall cofferdams with heights up to 6.50 m. The length of the planned inflow and outflow weirs structure enables an inflow discharge of Q = 330 m³/s. For the regulation of the groundwater, pumping stations with a capacity of 500 l/s are designed as well as an extra pumping station with a capacity of 2 m³/s for the emptying of the reservoir. The planning process started in 2004. The project is currently in the governmental planning approval procedure. The estimated construction costs are 70 Mio. €.

5.2.3 *Bislich-Vahnum/Wesel*

One of the utmost downstream locations for the creation of additional flood retention volume at the Lower Rhine is situated at the settlements of Bislich-Vahnum, an urban district of Wesel on the right side of the Rhine between Rhine-km 826.5 and 828.2. The potential utilization of the diked hinterland area was examined in a feasibility study in 2016. Because of the expected wide-ranging effects of the investigated measure, a work group composed of various stakeholders was established. In the course of this study several alternatives were investigated and evaluated in consideration of multiple aspects such as flood protection efficiency, nature conservation, industrial uses as well as aspects of agriculture and costs. The alternatives were compared and possible synergy effects were discussed. In conclusion it was not possible identify one favourable solution due to the competing interests of the stakeholders. Therefore, two favourable solutions were recommended for further consideration including one flood protection alternative and one alternative which was favourable in regard with nature conservation aspects.

From the perspective of the nature conservation, the complete relocation of the levee in conjunction with a utilization of the completely available area for flood retention purposes without control is favorited. This solution implies the construction of 3.2 km of new embankment dams/levees. In contrast, from the perspective of the flood protection a controlled flood polder with the same area is favorited. For this purpose new embankments have to be constructed as well as the existing levee rehabilitated in consideration of the future requirements. Furthermore, an in- and outflow structure have to be built. The potential polder volume amounts to 6.5 Mio. m³ for both solutions. The estimation of the construction costs is approx. 16.4 Mio. € for the levee relocation solution and 25.3 Mio. € for the realisation of the controlled flood polder.

5.3 Levee Rehabilitation Projects

5.3.1 *Grieth-Knollenkamp/Kleve*

Grieth is an urban district of the city Kalkar which belongs to the county Kleve and is located about 20 Rhine-km upstream of the Dutch border. The length of the levee is 3.3 km and shows a maximum height of 4 m. The levee crest hosts a superregional road which connects Wisselward and Grieth and which also had to be rehabilitated according the present requirements of road construction.

In this context a special cross section divergent to the standard levee profile of the district council Duesseldorf had to be developed and applied. The special levee section is also designed as a three-zone–levee section but without a berm on the downstream slope of the embankment. Flood defence works have to be executed from the road on the crest. The construction costs of the project were 11.5 Mio. €. The planning process lasted from 2015 to 2016 for the preparation of the execution design. The construction works were more or less finished in 2019.

5.3.2 *Griethausen/Kleve*

Griethausen is located almost directly at Dutch border at Rhine - km 857.0. The concerned levee sections shows a length of about 1.7 km. Similar to the situation in Grieth, there is also a road on the levee so that a special levee section needed to be designed. Only a crest road was assumed to be required which also enables the owner to execute levee defence measures.

A challenge of this project was the crossing of the Spoy channel and a two old ship logs. Both ship logs and the present pumping station are historical important construction monuments which are protected by law.

The planning started in 2016 and is currently in the planning approval process of the district council. The construction costs were estimated to be not less than 20 Mio. €.

5.3.3 *Baerl/Duisburg*

The rehabilitation project of this Rhine levee is located between Duisburg Baerl and Orsoy. The project includes levees with a length of 4.6 km. Due to the scarcity of area the use of different rehabilitation designs were considered. In the urban sections the structural stability is planned to be realised by the implementation of a static equivalent system in form of steel sheet piles. In the agricultural area the demolition of the existing levee and the construction of a three-zone standard levee section is favoured.

Aspects of groundwater and mining subsidence which are the reasons for the enormous levee heights of up to 15 m and have to be considered during the complete planning and design stage. Therefore, the impact of the levee rehabilitation on the groundwater situation will be examined in detail by groundwater modelling. The construction costs of the project are expected not to be less than 20 Mio. €. The levee rehabilitation shall be finished until the end of 2025 according to the levee rehabilitation roadmap.

6. CONCLUSION

The Lower Rhine Area shows the highest flood damage potential of Germany. Furthermore the former mining activities have led large levees and low hinterland areas for which flooding would be critical and would result in long-term consequences. As shown in Figure 3 the realization of flood retention projects is under progress, thus, the target of the Integrated Rhine Program in the close future seems realistic. Besides the herewith caused reduction of the flood levels also the rehabilitation works of the large levees is ongoing according to the established roadmap. The district council intends to rehabilitate the levees and flood protection structures according to the state of the art until 2025. The described case studies provide a short impression of the project contents and the realisation status.

Due to the enormous damage potential in combination with the special situation of the lower Rhine region in regard with the potential consequences of a levee failure, the importance of modern sustainable and integrated flood protection management as well as absolutely safe, durable and reliable flood protection structures are underlined.

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