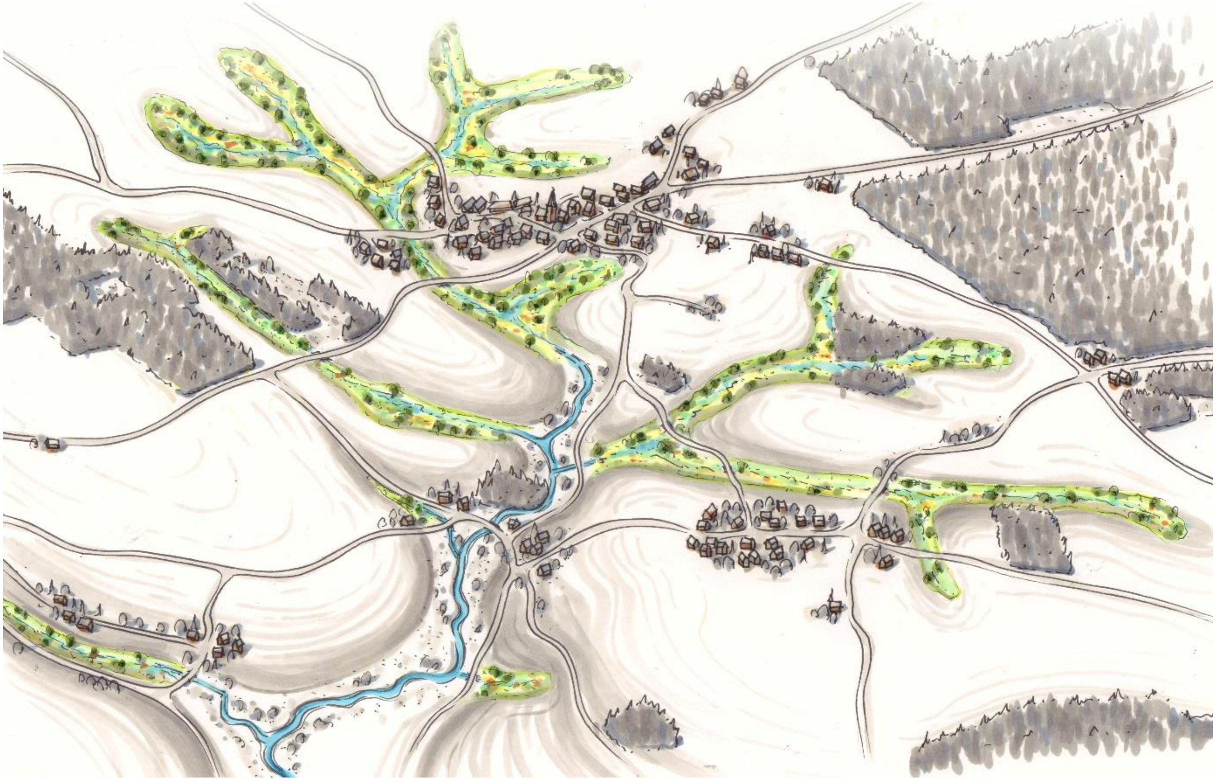
Micro Catchments, Macro Effects

Natural retention in the Rhine catchment as a nature-based solution for flood risks, drought control, biodiversity restoration and climate challenges.



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1. Introduction

Restoration of natural retention (wetlands) in the German Middle Mountains reduces flood and drought risks, and CO_2 emissions in the international Rhine basin. It also increases biodiversity, improves water quality and strengthens Europe's green infrastructure. As such it contributes to multiple EU policies such as the Water and Floods Directives, European Green Deal and strategies on Biodiversity and Adaptation to Climate Change, as well as national goals. Though the intervention involves a maximum of 2.7% of the Rhine basin, the effects are widespread because measures are taken literally at the source. This, added to the fact that implementation is relatively simple and takes place on marginal agricultural grasslands, leads to a positive societal benefit-cost ratio.

Most European rivers have been "normalised": meanders were cut off and lateral floodplains narrowed, mainly to improve conditions for navigation. The Rhine is no exception to this. The negative side-effects: quicker discharge of water, leading to higher flood risks, longer periods of drought and the loss of biodiversity. These problems are widely recognised and on the agenda of national governments and institutions like the International Commission for Protection of the Rhine.

This concise report, in an article format, is substantiated by the following background reports that are included in the appendix.

- Wetland restoration impacts on streamflow and water quality in Kyll river catchment, Germany, Acacia Water, 2021
- The effects of wetland restoration on ecosystem services in the German Middle Mountains, Thesis Olaf de Haan, 2021

1.1 Micro catchments, macro effects

At least as important but less known, is that the micro-catchments of large rivers have changed dramatically over time as well. Marshy, upstream valley parts used to function as "natural sponges", temporarily storing water from heavy rainfall, before gradually releasing it as small and steady streams. It is important to know that not only rainfall and snow falling in the valley itself was buffered, but also precipitation from the much wider, uphill surroundings. Because of this, a relatively small patch of wetland on the valley floor had a disproportionally large, regulatory effect. But all across Europe, many of these crucially important wetland areas have been drained[1]. The steady flows of water emerging from them changed into strongly pulsating streams, responding almost immediately to changes in rainfall with higher occurrences of both flooding and droughts, on local, regional and (inter)national scale. This already causes greater risk from floods and droughts, and without action these problems will increase due to climate change resulting in both more erratic and intense precipitation patterns, and thus even larger fluctuations in river discharge.

[1] https://media.stroming.nl/sponges/

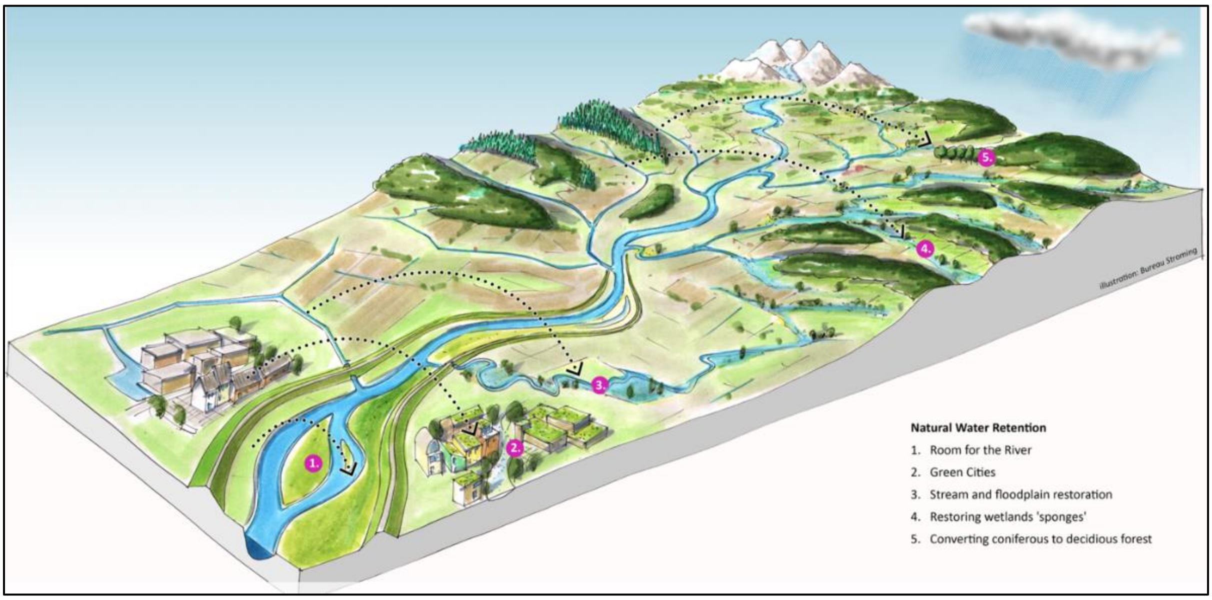

Fig. 2.1. Restoring upstream wetland areas preserves rainwater near the source (number 4). By undraining upstream valleys in the Rhine basin the entire downstream region can benefit. It is one of several nature-based solutions to restore the natural hydrology and ecology of the river.

2. NATURAL WATER RETENTION MEASURES:

RESTORE NATURAL SPONGE CAPACITY OF THE SOIL

The intervention needed to remedy this is relatively simple: if in suitable areas existing drainage channels are blocked a much larger fraction of the precipitation will start infiltrate the soil again and travel downwards as a much slower, subsurface flow. As a consequence, a smaller proportion of the precipitation will travel as a fast overland flow[2]. In the circumstances that precipitation intensity exceeds the infiltration capacity of the soil, overland flow still remains the dominant discharge process. It will however be slowed down by natural vegetation in comparison with the fast-flowing drainage channels. As a result, the simple intervention of blocking drainage canals in relatively small parts of the river basin can be expected to result in an overall reduction of stream velocity and hence a reduction of both flood peaks and droughts.

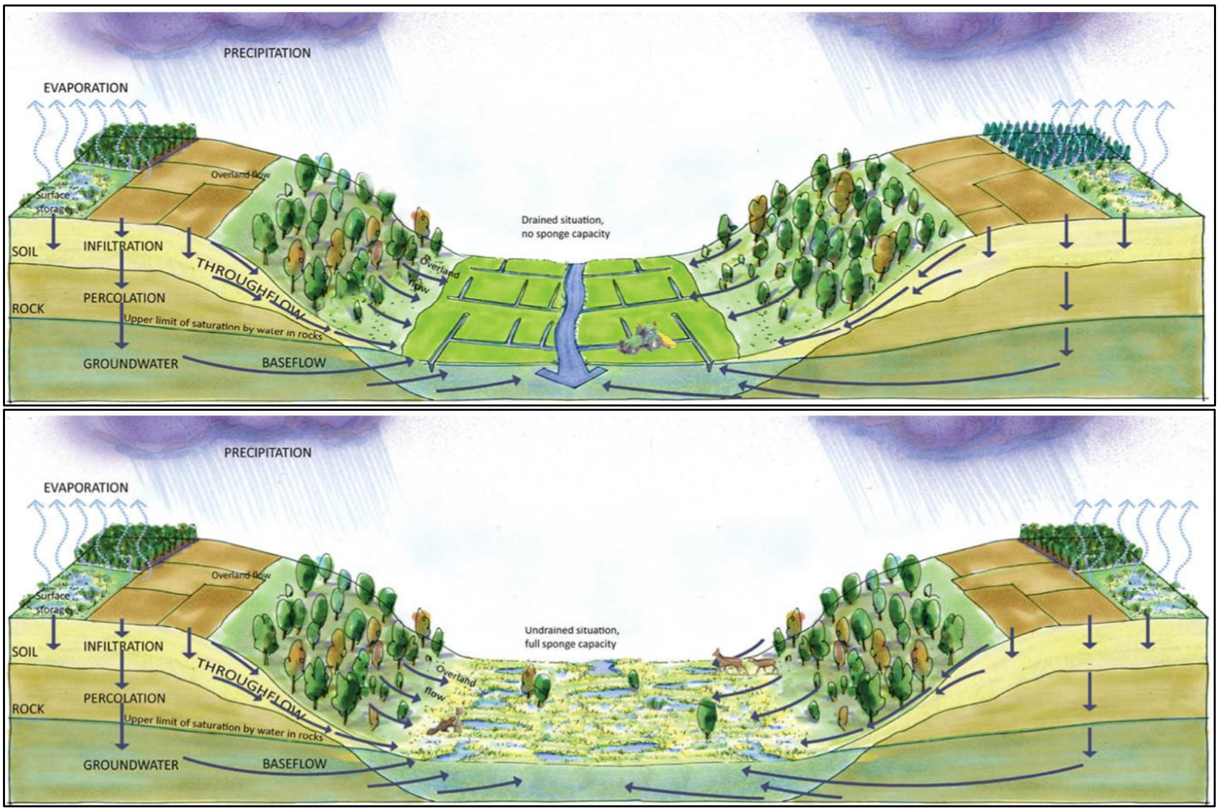

Fig. 2.2. Systemic impression of restoration of natural water retention, before (above) and after restoration. It requires removal of existing drains, resulting in drastic reduction of discharge peaks in the upper parts of a river basin. These effects are noticeable at local, regional and (inter)national level.

2.1 Research questions

Whereas it is easy to grasp the concept of restoring natural retention, it is more difficult to tell how large the effects would be: how much can peak flows and periods of droughts be reduced and will an intervention in the uphill capillaries of the river still have noticeable effects tens or even hundreds of kilometres downstream? What would be the effect on water quality, to which EU policy objectives would it contribute and how much would it cost?

[2] https://www.stroming.nl/sites/default/files/2017-02/Possibilites%20for%20storage%20120813.pdf

These questions have been addressed by a consortium of NGO's, research institutes and consultancies[3] in a series of studies. The Rhine basin was taken as the study area and the approach consisted of 4 steps:

(1) calculation of hydrological effects of natural water retention on micro-, meso- and macroscale

(2) translation of hydrological effects into effects on water quality

(3) using the outcomes, combined with information from other sources, to investigate the potential contribution to relevant EU policies

(4) elaborating a rough societal cost benefit analysis and a business case.

The results obtained to date are summarised below.

[3] Wetlands International – European Association, World Wide Fund for Nature, Deltares, Hydrologic, Acacia Water, Stroming and Reishner.

3. HYDROLOGICAL EFFECTS

Within the international Rhine basin, the German Middle Mountains receive relatively large amounts of precipitation. Therefore, the middle mountain region plays an important role in generating flood peaks and droughts in the middle and lower sections of the river Rhine, particularly in Germany and the Netherlands. The study area, the Steinebrück catchment, is situated in this hydrologically important region. It is the most upstream catchment of the river Kyll, which in turn is a tributary to the Mosel River and eventually the Rhine.

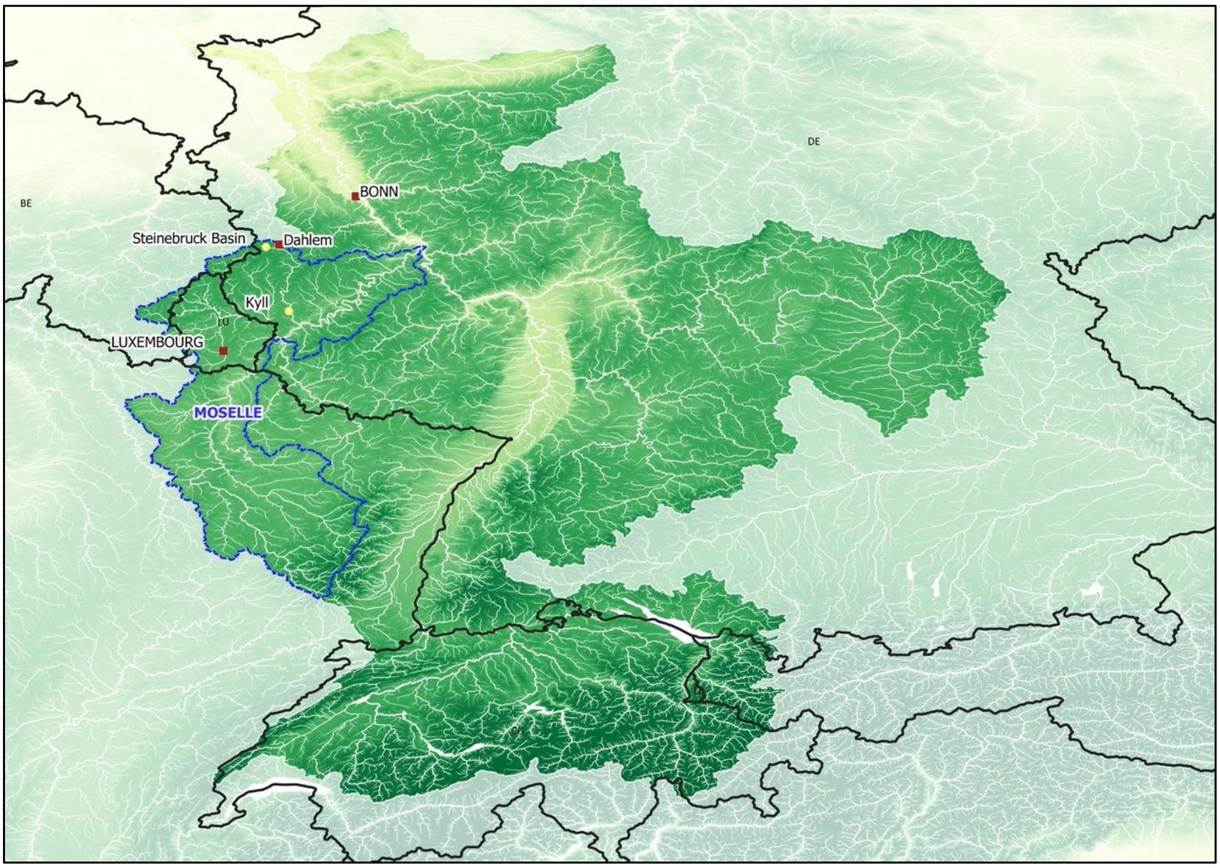

Fig. 3.1 Map with location of Steinebrück study area, the Kyll river and the Mosel basin (blue border).

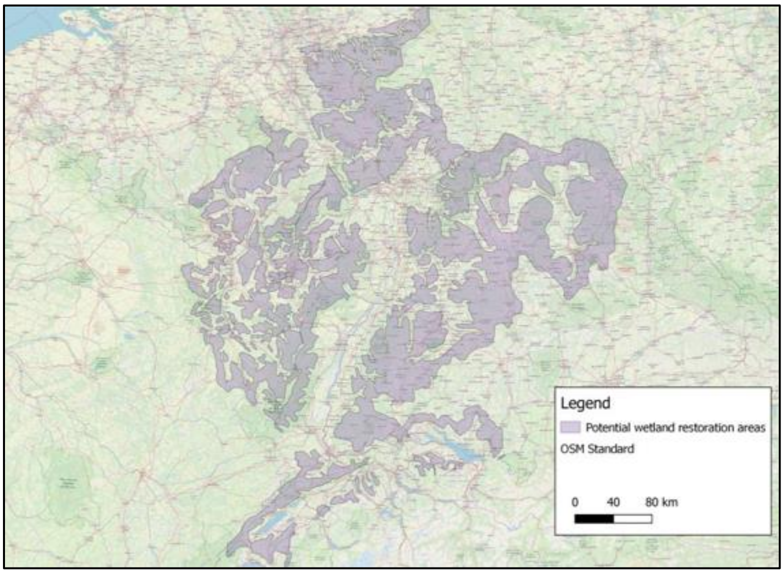

Fig 3.2. Zones within the Rhine basin with potential for wetland restoration. These grey zones were included in the hydrological, macro-scale calculations.

Within the 48 km^2 Steinebrück catchment, five micro-catchments were identified and three of those, covering a total of 18 km^2 (38%), were used to calculate the hydrological effects of natural water retention. A previous study[4] showed that on average 4-8% of a sub-basin in the Middle Mountains is suitable for natural water retention, i.e., with relatively low slope (<10%) and not built up with housing or commercial buildings. This also proved the case in the three Steinebrück micro catchments, where 5-7% (average 6%) was suitable for natural water retention.

Calculations for the three micro-catchments were done with a SWAT+ model, under the condition that the full 6% of potentially suitable areas for wetland restoration were undrained and restored as "natural sponges"[5]. The outcomes of this modelling exercise were subsequently used as input for calculations with a WFLOW model, generating outcomes on the higher scale levels of the Mosel and Rhine.

3.1 Pronounced effects

The effect on micro scale appears strong: removal of drainage systems in 6% of the area in a micro-catchment results in a 20-30% lower maximum peak flow emerging from that micro-catchment, whereas low flow (an indicator for drought reduction) increases by 10-30%. For the Steinebrück catchment as a whole, maximum peak flow reduction was 13%. This reduction in peak flow reflects that only 3 of the 5 micro catchments, i.e., 38% of the full restoration potential of the total Steinebrück catchment, was used.

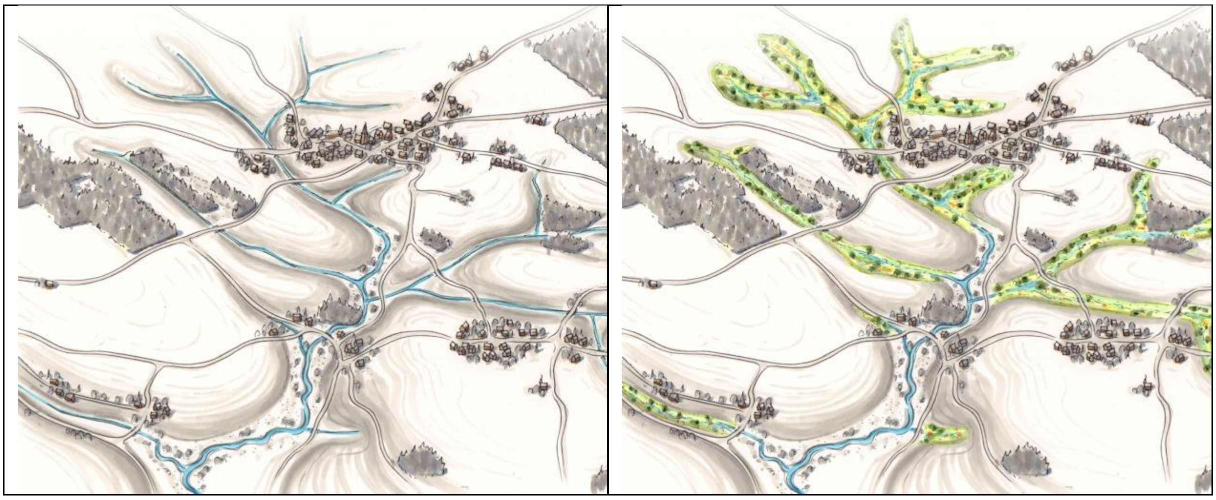

Fig. 3.3. Restoration of natural retention in a micro-catchment. Approximately 6% of a micro-catchment is suitable for natural retention.

On the scale of the Mosel basin, the effects were lower but still pronounced, with peak flow reductions a maximum of 4.1%. The maximum peak flow reduction at the Dutch/German border town Lobith was lower again: 1.8%. These decreasing values can be attributed to the fact that on the scale of a micro-catchment, the intensity and duration of precipitation are largely similar in the entire

[4] Otterman, E. et. al. 2017. Restoration of marshes in the valleys of the middle mountains of the Rhine basin for flood and drought risk prevention; "the sponges approach".

[5] For a full description of the study area and methods used: Waterloo, M.J. et al. 2019. Wetland restoration impact on streamflow in the Rhine River Basin. Commissioned by Wetlands International, World Wide Fund for Nature-Netherlands and Stroming Ltd.

area. If scale levels go up, this is no longer the case in a given time frame, with parts of the Mosel or Rhine basin receiving (heavy) rain whereas other parts remain dry. Soil and land-use conditions will vary as well when scale levels go up. An additional phenomenon is that peak flows from different tributaries reach the main river at different moments so that both peak flows and peak flow reductions cannot be simply added up

Whereas decreasing hydrological effects at higher scale levels are no surprise, also the results at higher scale levels are interesting (see also § 5 and 6).

3.2 Extrapolation

The outcomes for the Mosel and Rhine become even more interesting when considering that they reflect calculated peak reductions with only 38% of the retention potential being used. Because of time and budgetary restraints, a calculation for full use of retention capacity could not be executed, but it is certain that hydrological effects increase when more of the retention potential is used. Assuming a roughly linear relationship[6], full use of retention capacity could result in maximum peak reductions of 11% for the Mosel and 4.8% for the Rhine at Lobith.

Discharge emerging from:	Retention potential used	Max. peak reduction calculated	Max. reduction if potential fully used (see text)
Micro catchment within Steinebrück catchment	100% (= 6% of surface micro catchment)	30%	30%
Steinebrück catchment	38%	13%	ca. 30%
Mosel	38%	4.2%	ca. 11%
Rhine (Lobith)	38%	1.8%	ca. 5%

Table 3.1. Summary of maximum peak flow reductions that can result from restoration of natural retention at different scale levels in the Rhine catchment. The last column does not give the direct results of the calculations with SWAT+ and WFLOW but reflect extrapolations of those results and should be seen as indicative.

[6] This assumption could be considered plausible because WFLOW calculations already incorporated differences in meteorological, land-use and soil conditions in the large and varied Rhine basin (see fig. 3.2). Increasing the use of retention potential from 38% to 100% does not mean that micro-catchments *outside* of the study area (and thus new variability in meteorological, soil and land-use conditions) are drawn into the equation. It simply means that *within the suitable micro-catchments already part of the WFLOW calculations*, a larger fraction of the suitable areas is used. But in order to confirm this assumption, additional WFLOW calculations are necessary.

4. WATER QUALITY EFFECTS

The restoration of retention capacity slows down the transport of water and hence allows more time for vegetation and soil to absorb nutrients, so that the concentration and export of nutrients from a catchment is reduced. When water retention areas are restored as natural wetlands, water quality improves even further because inputs from manure and fertilizers stop. In the study area, the use of fertilizer and manure is already limited at present so that water quality improvements are largely caused by reduced stream velocity. Reductions in nutrients in the micro catchments in which retention capacity was restored were[7] on the order of 50% for Nitrogen (N) and 65% for Phosphorus (P). Peak levels, which are particularly important for biodiversity since high levels of nutrients contribute to turbidity and the potential occurrence of blue-green algae, are reduced as well. Daily maximum N and P exports show considerable decreases of 28-60% for N and 52-69% for P for the wetland scenario in the project areas.

[7] Waterloo, M., A.I. Gevaert and L.A.Q.M. Onderwater. 2021. Wetland restoration impacts on streamflow and water quality in the Kylldal river catchment, Germany.

5. SOCIETAL COST BENEFIT ANALYSIS

Avoiding floods and periods of droughts as well as improving water quality represent important societal benefits. A social cost benefit analysis provides a more complete – though never full – picture of the relationship between benefits and costs involved. The largely qualitative approach presented here, a diagram, follows a method applied by Ecorys/WWF[8] in a social cost-benefit analysis of the "Living Rivers" concept. It shows the consequences of an intervention on three levels: (1) state change (2) physical effects (direct effects), (3) effect on society/socio-economic effect (valuation).

The diagram in fig. 5.1. presents this on the scale of the Rhine basin in qualitative terms and (partly) quantifies this for the Steinebrück catchment. These details are then used to outline a business case and pilot for that particular catchment (section 6).

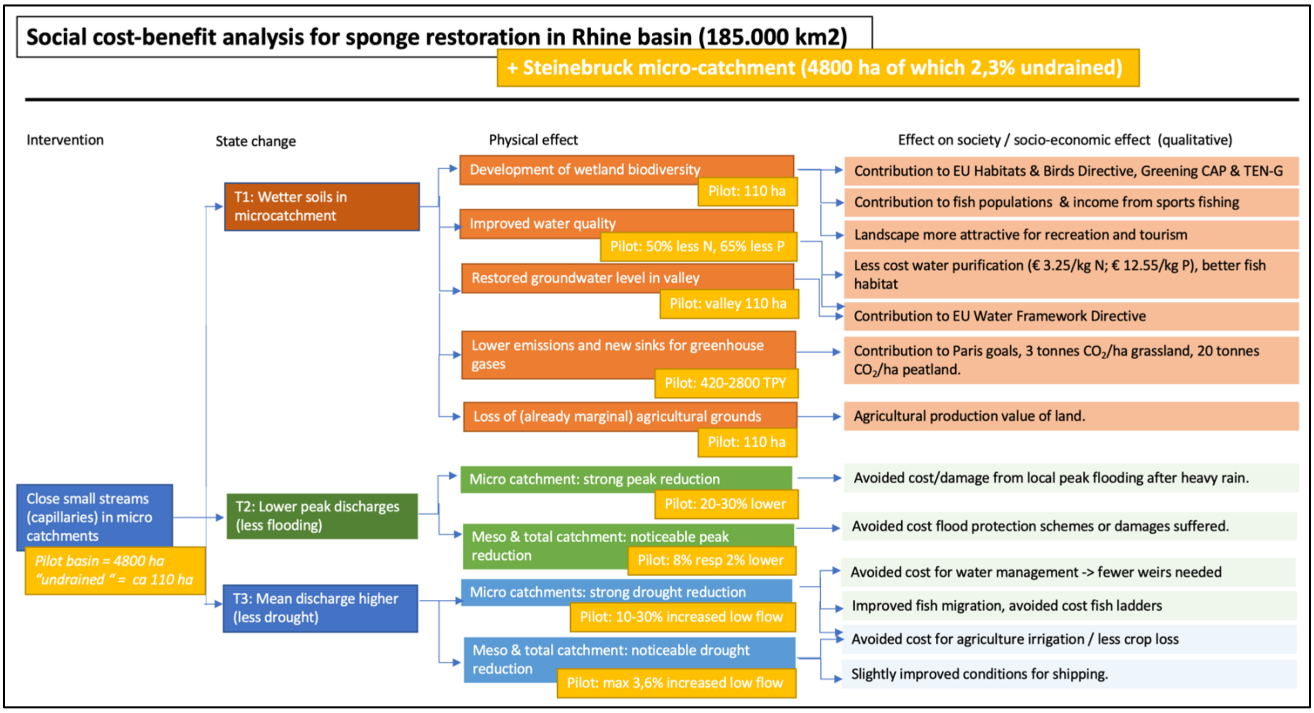

Fig. 5.1. The diagram shows, in qualitative terms, the social benefits and costs for restoration of natural water retention ("natural sponge capacity") in the Middle Mountains in Germany. Where possible figures have been added for the effects generated by the study area. These figures do not represent the full potential of natural water retention but show effects when 38% of the restoration potential is used.

The intervention is the removal of drainage in relatively small parts of the catchment in the upper regions of the river system. Research shows that approximately 2.7% of the international Rhine basin is suitable for this (see table 6.2). The Steinebrück catchment has a total surface of 4,800 ha, of which 110 ha (2.3%) is used for the intervention[9].

The state changes (T1 – T3) resulting from the intervention as well as the direct effects and valuation thereof are explained below. The three levels of catchment are distinguished. The Rhine catchment as a whole (macro catchment), the Mosel catchment and the catchment of the small streams feeding

[8] Ecorys. 2020. Werkwijzer MKBA Levende Rivieren. Commissioned by WWF

[9] If the full potential would have been used, undraining would have taken place in approximately 6% of the Steinebrück catchment.

into the Kyll and subsequently into the Mosel (micro catchment), in this case the Steinebrück catchment.

Wetter soils and related effects (T1)

Where smalls streams are blocked, precipitation penetrates into the soil and discharge will largely take place as slow subsoil flow. Once saturation levels are reached discharge also takes place as overland flow. When soil becomes wetter a rough, marshy vegetation develops which decreases overland flow and thus further enhances the retention. These combined effects also contribute to slowing down the discharge of heavy rains in the summer, an increasingly important phenomenon caused by climate change.

Wetter soils also result in the restoration of biodiversity for wetland habitats (including EU Habitats Directive priority habitat types[10]). The potential for the intervention in the Rhine basin as a whole is some 504,000 hectares (see § 6). Effects are not just local: the new fish habitat created by the intervention also benefits EU ANNEX II listed (partly migratory) species like Brook Lamprey, Great Loach, Atlantic Salmon, Bullhead and River Lamprey. Wetland restoration also contributes to the goals of the EU Birds Directive (such as Breeding and feeding grounds for songbirds, waders and waterfowl), the goals of greening the Common Agricultural Policy and the Trans-European Network for Green Infrastructure TEN-G. The increased biodiversity and more varied landscape also make the restored areas more attractive for tourism and recreation, including sports fishing.

Fig. 5.2 Picture one year after restoring the hydrology in an upstream rhine catchment in the Eiffel (by blocking drainage channels). The hydrologic intervention creates new habitats and benefits for species listed in the EU Habitats and Birds Directives.

Water quality improves as well (see §4). In the Steinebrück catchment annual nutrient loads were reduced on the order of 50% for N and 65% for P for the micro catchments in which retention capacity was restored. The monetary value of this can be calculated in terms of purification costs

[10] https://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

saved, as a proxy for the purification services provided by the wetland area[11]. Literature suggests € 3.25/kg N, and for P € 12.55/kg.

Finally, groundwater levels will increase as well, a further contribution to the goals of the EU Water Framework Directive.

Undraining small parts of the river basin also reduces greenhouse gas emissions such as CO_2 and CH_4. Natural grasslands typically store 3 tonnes CO_2/ha*yr, peatlands store 20 tonnes CO_2/ha*yr. It is expected that undraining will roughly lead to a 50/50 mix of wet grasslands (*Feuchtwiesen*) and peat. If the full potential (5,040 km^2) in the Rhine catchment is used, this translates into an annual CO_2 sequestration of 5,800,000 tonnes per year (TPY). Using an internal CO_2 price of € 100/tonne this represents a financial benefit of € 580 million per year. In the researched part of the Steinebrück catchment (ca. 110 ha "undrained") the average potential is 1,265 TPY, representing a financial benefit of roughly € 126,500/yr.

The intervention only takes place on marginal grounds. Yet, a negative benefit is the loss of value for agricultural production. Prices of this type of agricultural land vary, in the Steinebrück catchment the price is € 12,000/ha[12]. In the Netherlands as well as Germany, agricultural lands retain 20- 25% of their value when transformed into nature. The one-off investment needed to purchase the land therefore would be roughly € 9,300/ha and equals
€ 420/ha*yr using a discount rate of 4.5%. An alternative to the purchase of land is to lease, which is less costly at least in the short term (see § 6).

Lower peak discharges and flood risk(T2)

The hydrological effects described in § 3 can be summarised as follows. In micro catchments where the intervention takes place, the maximum peak discharge from that micro catchment is 20-30% lower than before the intervention. Where the intervention takes place, the density of human habitation is usually low, so the economic and social costs of flood reduction measures may be limited. Further downstream, population density increases with smaller villages, campsites and commercial buildings, here the flood prevention has more social and economic impact. This became painfully clear on the flooding event on the 14th and 15th July 2021 when large parts of the Eiffel and Ardennes were hit by extreme rainfall. Major flooding events occurred in catchments that usually have a summer discharge below 5 m3/sec. The Kyll river (Steinebrück is part of the Kyll river) was one of the catchments that had peak discharges that no one would have thought possible (figure 5.3 and 5.4). The total costs of the flooding are not yet known but are enormous.

[11] Braaksma, P.J. and A.E. Bos. 2007. Investeren in het Nederlandse Landschap. Figures quoted in this study date from 1999 and are € 2.20/kg N and € 8.50/P. Corrected for inflation this is € 3.25 and € 12.55 in 2020.
[12] Bodenrichtwerte (standard land values) as given by www.boris.nrw.de

Figure 5.3 The city of Kyllburg flooded by the river Kyll. Photo credit unknown.

Figure 5.4 A campsite near Kyllburg flooded by the Kyll river. Photo credit Mèlani Betten.

The hydrological effects on meso and macro basin level are less pronounced, but at the same time the amount of economic activity and population impacted grows as the scale increases.
The flood control potential of natural water retention gains context if compared to the Dutch “Room for the River” programme. This aimed to increase peak flow capacity of the Dutch part of the Rhine by 6.6% (from 15,000 to 16,000 m^3/s Lobith) against a total cost € 2.3 billion. On top of that, billions of euros were spent on the HWBP (High Water Protection Scheme) aimed at protection of the

coastline, but also including substantial (but not easily traceable) sums spent on river dikes. In addition, it should be noted that these measures only enhanced river safety in the Dutch part of the Rhine basin, whereas intervening upstream also contributes to river safety – and other goals – in the German part, including cities like Köln. In concrete terms: Room for the River protected the 25,000 km^2 of the Dutch part of the Rhine catchment, whereas natural water retention in the Middle Mountains could have a positive effect on the 125,000 km^2 in Germany, France, Belgium and Luxembourg as well, i.e., a 600% wider spread of benefits.

Higher mean discharge and less drought (T3)

The intervention of improved natural water retention increases the low flow of the streams at the micro catchment level by 10-30%. A steadier flow with fewer periods of drought is favourable because it improves water quality (see earlier under T1). Sponge restoration is a natural alternative to improve water availability in upstream areas and may there reduce the need for local weirs, which is favourable for fish migration and/or the cost for fish ladders.

Further downstream, on the meso and macro level of the Mosel and Rhine catchment as a whole, the efficiency on drought reduction is less strong but the impact of low water levels on power, agriculture and shipping are enormous. Natural sponge restoration mitigates or shortens periods of extremely low water levels in the river and the associated problems for navigation and shipping, and abstractions for agricultural irrigation and power plant cooling.

Rivers affected by drought lose more than water depth. Less rainwater means that river waters cannot dilute pollutants efficiently; this leads to higher concentrations of nitrogen and phosphorus, as well as of heavy metals and microplastics[13]. The organic build up boosts algal production, leading to blooms that could make the water unusable for human use. Hotter river waters also hold less oxygen than cold ones, which harms fish and other aquatic fauna.

[13] https://aboutdrought.info/about-us/projects/marius/

6. BUSINESS CASE

The previous paragraph provides the building blocks for a quantitative business case and outline for a pilot. The business case is drawn up for an intervention of 100 hectares. This roughly equals the size of the intervention in the Steinebrück catchment and would also be a sensible scale for a field pilot because it is large enough to obtain measurable results. It also is small enough to avoid a lot of variation in physical and meteorological conditions which could blur the results of the intervention.

An important cost factor is the purchase or lease of the land necessary for the intervention. Leasing the land (or annual compensation for production loss) has the advantage that cooperation will probably be easier to obtain and it aligns with the temporary character of a pilot. In the long run, it could be more cost effective and secure to buy the land – provided landowners are willing to sell. In both approaches it is important to realise that small surfaces are involved, and it is not a problem if these parcels are scattered throughout the valley. This means that compensation for the termination of agricultural enterprises is not applicable.

6.1 Costs and benefits

The table below builds on the diagram presented in fig. 5.1 and shows costs and benefits for an intervention on 100 hectares over 10 years. In financial terms the most important cost is the purchase or lease of land, the most important measured benefit is CO_2 sequestration.

Assuming a lease of ca 1.5 % of the land value[14] and an internal CO_2 price of € 100/tonne per year, this leads to a positive business case with a benefit/cost ratio of 2.4. Combining a 1.5% lease and a (ETF market) price for CO_2 of € 40/tonne per year[15], leads to a benefit/cost ratio of 1.1. If calculated with purchase of land against a 4.5% discount rate, a decrease in land-value of 80% and an internal CO_2 price of € 100/tonne, the benefit/cost ratio is 1.5.

[14] Lease prices in 2016 were 1.0% and 1.75% of the land value in Nordrhein-Westfalen and Rheinland-Pfaltz respectively (source: Praxis-agrar.de).
[15] The ETS market price on 9 April 2021 was slightly above € 43.5/tonne, on 10 June 2021 it was € 53.78/tonne.

Cost in case of lease of land (per 100 hectare per decade, rounded figures)								
	rate	quantity	unit	price/unit	surface (ha)	years	Costs/decade	Remarks
Lease of land	1,50%		ha	€ 12.000	100	10	€ 180.000	See note [1]
Project execution & equipment						10	€ 25.000	Closing ditches, flow meters + maintenance
Project management		0,1	fte	€ 125.000		10	€ 125.000	0.1 fte + out of pocket * 10 yr
Monitoring		0,1	fte	€ 125.000		10	€ 125.000	0.1 fte + out of pocket * 10 yr
Development cost						10		See box
Unforeseen	20%					10	€ 91.000	20% of above
Total cost						10	**€ 546.000**	
Loss of agricultural production								Not applicable because of lease
CO_2 sequestration		11,5	ton/yr*ha	€ 100	100	10	€ 1.150.000	See note [3]
Less N		0,178	kg/ha*yr	€ 3,25	100	10	€ 579	
Less P		0,025	kg/ha*yr	€ 12,55	100	10	€ 311	
Avoided cost flood control downstream	4,5%	0,02%	% peak reduction	€ 1.660.000.000		10	€ 149.400	See note [4]
Avoided cost drought control & irrigation						10		Unknown
Extra income tourism			€/visitor	€ 5	100	10	5000	See note [5]
Avoided cost fish ladders and dams						10		Unknown
Other benefits						10		See note [2]
Total benefits						10	**€ 1.305.290**	
Balance							€ 759.290	
Benefit/cost ratio							2,4	
[1] Lease prices are likely between 1,0% and 2%.								
[2] contribution to EU Habitats, Birds, and Water Framework directive, mitigation of low-flow problems such as in shipping, agricultural irrigation and cooling of energy plants								
[3] Assuming the vegetation will become a 50/50 mix of natural grasslands and peatland.								
[4]The Dutch Room for the River programme provided 6,6% discharge capacity against € 2,300 million, i.e. € 350 million per percent. If all suitable areas would be undrained in the Rhine basin, this could generate a 4,75% decrease in peakflow at Lobith, worth € 1,660 million. An area of 100 ha represents 100/504,000 = 0,02% of this.								
[5] An international study (TEEB), has ranked income from tourism and recreation. The numbers were based on multiple studies. For rivers, lakes and marshes, the potential for tourism varies between €5 and €3,000 per hectare per year. Russ, D. et. al. 2013. The Economics of Ecosystems and and Biodiversity of Water and Wetlands.								

Table 6.1. The societal costs and benefits for restoration of natural retention on the basis of a 100-hectare plot, over 10 years.

Cost and benefits of a field pilot
With a few adaptations table 6.1 also provides insight into the cost of a pilot. The cost would be higher because a pilot would require a more extensive development phase, which could be estimated at € 250,000 (1 fte and out of pocket cost for the first two years). Given the 2 years preparation, the benefits would be lower since they would be limited to a period of 8 instead of 10 years. Though research efforts should not be judged on the basis of short-term benefits, even a field pilot could already have a favourable benefit/cost ratio and at least provide more detailed knowledge on this.

6.2 Financing

Natural water retention has many societal benefits, so it is realistic to assume that governments are the primary funding source for social goals, like clean water, river safety, drought and flood control, biodiversity, and climate change adaptation and mitigation (table 6.4).

However large economic sectors such as energy and drinking water, inland navigation and industrial production are dependent on flows in the Rhine River. Additionally, the Dutch Court of Justice substantially upgraded the well-known “polluter pays” principle when it instructed Royal Dutch Shell to accept the Paris climate goals as the framework for its worldwide business operation. In practical terms this means that the company is now obliged to redirect its investments towards a modus operandi that achieves a crucial social benefit: a safe climate. This means that already in the medium-short term, business capital could be an additional funding source for natural water retention.

A substantial and promising link between natural water retention and market capital is the potential for CO_2 sequestration. Each hectare of natural retention developed can be expected to retain 11.5 tonnes of CO_2 per hectare per year and even at current ETF market prices – which are expected to further increase – a positive business case is feasible. To turn this *potential* revenue into *real* revenue the CO_2 sequestration potential of natural retention needs to be validated: will indeed 11.5 tonnes of CO_2 be sequestered per hectare? It also needs to be certified so that issuing of CO_2 certificates becomes possible. The feasibility of this approach has already been demonstrated by the Netherlands' Valuta voor Veen (Currency for Peat) and this could serve as a model. It is a voluntary scheme which sells certificates for € 70/tonne and results in landowners receiving a compensation of up to € 800 per hectare per year. An alternative approach is to work towards inclusion of natural water retention in the government's schemes for CO_2 sequestration. In Germany the potential is large. Drained bogs make up only 7% of the agricultural area, but they cause 99% of CO_2 emissions from agricultural soils and 37% of all emissions from agriculture as a whole.[16]

In order to stimulate the market driven development of natural retention and the rapid upscaling and deployment, a 3-step strategy could be followed, along the following lines:

Step 1: EU/Government funding will enable the further development of the concept by setting up one or more field pilots to (a) discover and surmount practical implementation hurdles and (b) validate the concept and in terms of social benefits, including (but not limited to) water retention and CO_2 sequestration and (c) improve models used to calculate the large-scale potential on the basis of field pilot data. The funding needed in this step could either come from JRC of the European Green Deal Investment Plan (EGDIP), also referred to as Sustainable Europe Investment Plan (SEIP).

Step 2: EU/Government and/or the European Investment Bank funding will enable certification of the CO_2 sequestration potential for natural retention. Inclusion of certificates in either a voluntary or mandatory (Government/ETS) system need to be explored. If EIB-funding is not feasible at this stage, technical cooperation with experts of the EIB should ensure a solid concept, which in principle would fulfil criteria for EIB funding in step 3. If needed, a vehicle (e.g., a Ltd or Foundation) for purchase of the certificates should also be set up at this stage.

Step 3: European Investment Bank and/or EGDIP/SEIP funding will buy pre-financing of financing CO_2 certificates linked to natural retention as a sign of confidence.

The different steps could be taken simultaneously.

6.3 Upscaling to the Rhine basin

In the Steinebrück basin 5-7% of the total surface is suitable for the development of natural water retention. In the entire Rhine basin this percentage is lower because some areas are too steep, others are built up and yet other regions are too far downstream. It is estimated that a total of roughly 500,000 hectares in the total Rhine catchment has potential for natural water retention.

[16] UBA (2016): Reporting under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2016 . National inventory report on the German greenhouse gas inventory 1990 - 2014. 1040 p. (PDF)

Surface areas Rhine catchment how much is suitable for natural retention.	km2	subtotals	% of total
Rhine catchment (CH, F, D, NL)	185.000		100%
CH part-too steep & buffering lakes, NL part too downstream & dikes	45.000		
		140.000	76%
In approximately 40% no flat valley floors	56.000		
		84.000	45%
Ca 94% of remaining area too steep (slope >10%) or built up	78.960		
		5.040	2,7%

Table 6.2. A total of 504,000 hectares within the international Rhine basin is potentially suitable for the development of natural retention ("sponges").

Assuming prices for the relatively poor agricultural grasslands needed for natural water retention are more or less the same throughout the Rhine basin, also assuming full cooperation of landowners and, finally, assuming that societal benefits of natural water retention show linear correlations with the surface area involved the positive result for restoring natural retention throughout the Rhine basin would be roughly € 3.8 billion per year.

Jobs and business opportunities
Although the effects of natural water retention on the economy at large and maintenance or creation of jobs was not studied, it is interesting to quote a recent study of the World Economic Forum[17]. It distinguishes 3 socio-economic systems that need changing in order to balance ecology and economy: (1) food, land and ocean use (2) infrastructure and the built environment and (3) energy and extractives. It concludes that the first system is the most urgent, cost-effective and efficient to transform: it is currently the largest threat to nature, its transition requires a 2-3 times lower investment than the necessary transitions in the other two systems and it creates more business opportunities and substantially more jobs.

6.4 Sensitivity analysis

One of the difficulties with cost-benefit analysis involving ecosystems services is that the monetary value for all ecosystems is not known. In contrast, the direct costs for interventions are well known. Because of this, benefit/cost ratios almost inevitably underestimate the societal value of nature-based solutions.

A further complication is that, if data on the benefits of ecosystems services do exist, values in literature vary considerably. An example illustrating this comes from a TEEB study[18] on the value of water and wetlands. This calculates the total benefit of the provisioning, regulating, habitat and cultural services of inland floodplains, marshes and peatlands at approximately € 36,500 per hectare per year (2007 values). Using this figure, a 100-hectare area would generate € 3.65 million, reflecting a current value of € 4.5 million per year or € 45 million per decade[19]. These values are significantly higher than the outcomes presented in table 6.1.
A graph presenting the UN development goals in a hierarchical order, illustrates the imperfection of social cost-benefits analysis in another way.

[17] World Economic Forum. 2020. The future of nature and business.
[18] Russ, D. et. al. 2013. The Economics of Ecosystems and Biodiversity of Water and Wetlands.
[19] https://www.cbs.nl/nl-nl/visualisaties/prijzen-toen-en-nu

Fig. 6.3. Illustration showing that that economies and societies are seen as embedded parts of the biosphere. Social cost benefits tend to overestimate the value of the higher parts of the "wedding cake", whilst the lowest part by definition is of higher value because it is the basis for our economic and social wealth. Credit: Azote Images for Stockholm Resilience Centre, Stockholm University.

Apart from these structural difficulties, the cost benefit analysis presented here is sensitive to variations in prices of land. Average prices in the German part of the Rhine basin, for good and poor soils, grasslands and arable land, vary between € 9,000 – € 32,000/ha. The price (margin) of grasslands is lower than of arable lands and since only marginal lands are needed it can be expected that prices will concentrate in the lower part of the range. The value attributed to CO2 sequestration is also an important variable: the market value (ETS) at the time of writing is around € 43/tonne per year, the internal value often recommended is € 100/tonne per year with a future value (2050) of € 1000/tonne per year.[20] Prices attributed to the value of P and N loads avoided vary as well[21] and can be as low as € 0.61/kg P and as high as € 15/kg P. For N the low estimate is € 3.11/kg N.

A specific challenge in the case of interventions in river basins is that an intervention upstream by definition has more widespread effects than an intervention downstream (see § 5).

6.5 Policy contributions, a crucial part of the business case

Value and monetary value are two different items, that much is clear. One of the consequences is that direct business revenue and thus market financing is often lacking for important parts in the equation. Therefore, it is important to also know how natural retention contributes to Government policies.

An analysis of national and regional policies in the international Rhine basin was beyond the scope of

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[20] Cpb/PBL. 2016. WLO klimaatscenario's en de waardering van CO2 uitstoot in MKBA's.
[21] CE-Delft. 2017. Environmental Prices Handbook.

the study, therefore table 6.4 only shows EU policies to which the development of natural retention areas contributes. It indicates that financing for the development of natural retention could come – and would be legitimate – from various EU sources, the more so because a euro spent on this specific intervention contributes to multiple EU goals.

EU Policies	**Contribution**
Birds & Habitats Directives	- Improves the status of species and habitats towards a favourable conservation status. - Restoration of wetlands, including peat, alluvial forests and peat as breeding and feeding grounds for songbirds, waders, waterfowl.
European Green Deal	- Contributes to the commitment to tackle climate change and achieve no net emissions by 2050 by sequestering CO_2. - Supports the ambition for the natural functions of ground and surface water to be restored, to preserve and restore biodiversity in wetlands and prevent and limit damage from floods.
Biodiversity Strategy	- Contributes to the goal of restoring degraded ecosystems, "in particular those with the most potential to capture and store carbon and to prevent and reduce the impact of natural disasters." - Can help meet the requirement that at least 30% of land should be protected by 2030, and significant areas of carbon-rich ecosystems should be strictly protected. - Meets the ambition for "nature-based solutions, such as protecting and restoring wetlands, grasslands and agricultural soils, [that] will be essential for emission reduction and climate adaptation."
Water Framework Directive	- Improves freshwater ecosystems through natural flow regulation and natural water treatment that contributes to the objective of good ecological status by the deadline of 2027.
Floods Directive	- Reduces flood risk by retaining water in the sponge landscape and reducing peak flows.
Farm to Fork Strategy Common Agricultural Policy	- Contributes to the goal of improving "environmental and climate performance, including managing and storing carbon in the soil, and improved nutrient management to improve water quality and reduce emissions."
Trans-European Network for Green Infrastructure	- Contributes to ecological corridors to prevent genetic isolation, allow for species migration, and maintain and enhance healthy ecosystems.
Strategy on Adaptation to Climate Change	- The restoration of sponges is explicitly recognised as a nature-based solution that is essential for sustaining healthy water, oceans and soils.
Drinking Water Directive	- Offers natural filtration of pollutants to protect human health from adverse effects of any contamination of water intended for human consumption.

Table 6.4. EU policies to which restoration of natural water retention capacity contributes.

7. Conclusion

The restoration of natural water retention (wetlands) in the German Middle Mountains is a viable ecosystem-based solution to improve the hydrological services of catchments. It reduces flood and drought risks in the Rhine basin, with strong local effects, favouring the chances for local cooperation. Similar effects can be seen at regional and international scales, less strong but still pronounced, and more so if broader benefits are taken into account: decreased CO_2 emissions, improved water quality, increased biodiversity, the strengthening of Europe's resilience to climate change and a step towards a greener economy of no net emissions. As such, restoring natural water retention is a no regrets, nature-based solution that contributes to multiple EU policies as well as national goals.

Though the intervention involves a maximum of 2.7% of the Rhine basin, the effects are widespread because measures are taken literally at the source. This, added to the fact that implementation is relatively simple and takes place on marginal agricultural grasslands, leads to a positive benefit-cost ratio for natural water retention.

Development and implementation of a field pilot is the single most important recommendation right now to further develop the concept. The systematic collection and analysis of field data over a number of years will improve and solidify the insight provided by the studies summarised here, including results of hydrological modelling. In addition, setting up a field pilot will show how to best implement the concept in cooperation with landowners and other stakeholders.

8. Appendix

Background reports written for the JRC project:

- Wetland restoration impacts on streamflow and water quality in Kyll river catchment, Germany, Acacia Water, 2021

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Wetland_restoration_t

- Stakeholder analyses Steinebrück catchment, Germany, Ingenieurbüro Reihsner, 2021

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- The effects of wetland restoration on ecosystem services in the German Middle Mountains, Thesis Wetland International, Olaf de Haan, 2021

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Effects of Wetland res