Natural water storage in the Rhine basin as a solution for flood and drought control.

An expert judgment of the potential effectiveness of ‘natural sponges’.

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stroming

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1. Introduction

Importance and costs of flood control

Water management becomes increasingly important, throughout the world but in particular in regions like Europe because of 4 aspects, which reinforce each other:

- high population densities, which are still growing and in particular are concentrating in cities often within reach of river. In other words: the number of people potentially affected by flooding or droughts is very high.
- high and increasing levels of investment, which also tend to concentrate in areas vulnerable to flooding. In other words: the economic damage potentially caused by flooding (less so droughts) is extremely high.
- climate change is under way and expectations are that this will lead to higher river discharges and prolonged periods of drought.
- water managers have been active in flood and drought control for decades or even centuries. Every time a new step in water management was deemed necessary, the parties involved – when given a choice - have opted for the one that gives the "biggest bang for the buck". This means that the cheapest measures in most cases have already been implemented and are getting out of stock. In other words: reducing flood risks or droughts with X% is much more expensive now than it was before and this will continue.

All of the above is applicable to the Rhine Basin, the focus of this report, and illustrates clearly that is becomes increasingly important to ensure that a euro spent on flood control will not only generate safety but also other benefits like nature, space for leisure, new business opportunities.

Costs for flood control go up

Up till 1995 the Netherland's part of the Rhine was capable of safely channeling a discharge of 15.000 m^3/s arriving at the German/Dutch border to the North Sea. After serious floodings in 1993 and 1995 it was decided that the discharge capacity needed to be increased to 16.000 $m^{3/}$s. The almost completed (2015) programme "Space for the River" uses a budget of 2,3 billion Euro to achieve this. With this amount <u>both river safety and environmental quality</u> is enhanced.

Within the Delta Programme (under development) it is suggested that a further increase in necessary: the capacity should be increased to 17.000 m^3/s and in future possibly 18.000 m^3/s. The costs for the step from 16.000 m^3/s to 17.000 m^3/s have been estimated at 2,5 – 7 billion euros @. The lower estimate relates to a dike-strategy in which environmental quality will at best (but are unlikely) to stay at the current level. The higher estimate relates to a strategy that continues the "Space for the River" approach in which both river safety and environmental quality are increased.

In Germany 5,7 billion euro's will be spent on flood control till 2021.

Can restoration of natural sponges be an effective strategy?

There are clear indications that restoration of the sponge capacity in middle mountains, i.e. the capacity of soil and vegetation to store and slow down the run-off of precipitation, will lead to lower peaks, and thus lower flood risks in streams and the river. Furthermore sponges are likely to extend the period in which water is fed to streams and subsequently to the river. This may reduce the length of dry periods, but strong indications confirming this are lacking.

Although there is little disagreement as to whether restoration of natural sponges can lower flood discharges, there is debate when it comes to answering the question: can this be an effective strategy for flood and drought control. This debate is partly fed by the fact that computer models (mostly a combination of SOBEK and HBV) often 'show' that restoration of natural sponges cannot be expected to reduce flood peaks. However: current models are not suitable for 'calculating' the effectiveness of sponges (see http://www.stroming.nl/pdf/RijnCor-Brochure01072013.pdf). This same brochure explains, to the contrary, why it is likely that relatively small interventions in middle mountains can make a big difference.

Purpose and status of this report

The only way to be able to state with full certainty how effective a restored sponge is, is through field measurements (see http://www.stroming.nl/pdf/RijnCor-MogelijkhBergen%2020130507.pdf). It is however possible to make an educated guess. This – nothing more, nothing less – is what is presented in report, (see also Annex I):

- on the basis of readily available data on (desirable) river discharges a rough calculation is made of the surface area needed to make a difference on high water levels in the river
- prices of land are provided and used for a rough calculation on what it would cost to lower flood levels in the river;
- very roughly indication is given of the costs of reducing flood risks through traditional methods (building dikes)
- 2 and 3 are compared and – with great caution –something initial thoughts are provided on the (cost) effectiveness of sponges.

2. Technical context and scope

Technical approach and working with nature

There are several ways to reduce flood risks and control droughts. The distinction is often made between the ‘technical approach’ involving the building of dikes and pumps and a ‘working with nature approach’ such as restoring old river channels and meanders. Both approaches can be combined with goals relating to environmental quality and ecological restoration – it is important to keep that in mind. However, in this report we focus on the ‘working with nature’ approach.

Geographic focus

In this report the focus is on the international Rhine catchment. Within this catchment and within the ‘working with nature’ approach there is a wide array of measures that can be taken to influence floods and droughts. Possibilities in particular depend on the position of a given area in the river catchment. But before going in to that It is also important to know where, geographically speaking, floods and droughts originate.

In fact the Rhine has two sources of water: precipitation and the glaciers in the Alps providing a relatively stable flow of water. The latter is much more erratic and especially the absence or abundance of precipitation in the middle mountains is responsible for droughts and flooding. So, this provides us additional focus: we are looking for solutions in the middle mountain ranges in those parts of Germany, France and Luxembourg, which feed into the river Rhine.

Within that scope there are still various possibilities. In downstream-upstream order these are:

- tributaries of the Rhine, like Mosel, Ruhr, Neckar, and Kinzig, have like the Rhine itself been channelled. As a result water travels down with much higher speeds than before, resulting in higher flood peaks and longer periods of drought. Restoring river bends, allowing more natural vegetation on the banks are some of the measures that can help slow down the run-off of water in this section of the river.
- smaller streams like Kyll and Ruwer (feeding into the Mosel), Wenne (feeding into the Ruhr), Fils (feeding into the Neckar) and Gutach (feeding into the Kinzig) often flow through shallow valley plains: areas of relatively flat land on both sides of the river. Often these are used for agriculture and to protect these areas against the erosion the shores of these streams are often fixed, e.g. with stones. As a consequence the stream digs itself deeper into the soil – this is the only direction the erosive power can go. The increasing, vertical distance between the river and the valley plain makes it increasingly difficult for the river to flood the valley: the entire discharge remains in the deep river bed for a long period of time and travels downstream with high speeds. Removing the fixation of river banks in this part of the river bed can be an effective measure to reverse the process: the moment a stream floods a valley plain stream velocity drops drastically and thus decreases peak levels and flood risks downstream.
- the plateaus, slopes and upper valleys of the middle mountains of e.g. Eiffel, Hunsrück, Rothaargebirge, Swabische Alp en Black Forest receiving precipitation which eventually reaches the Rhine.

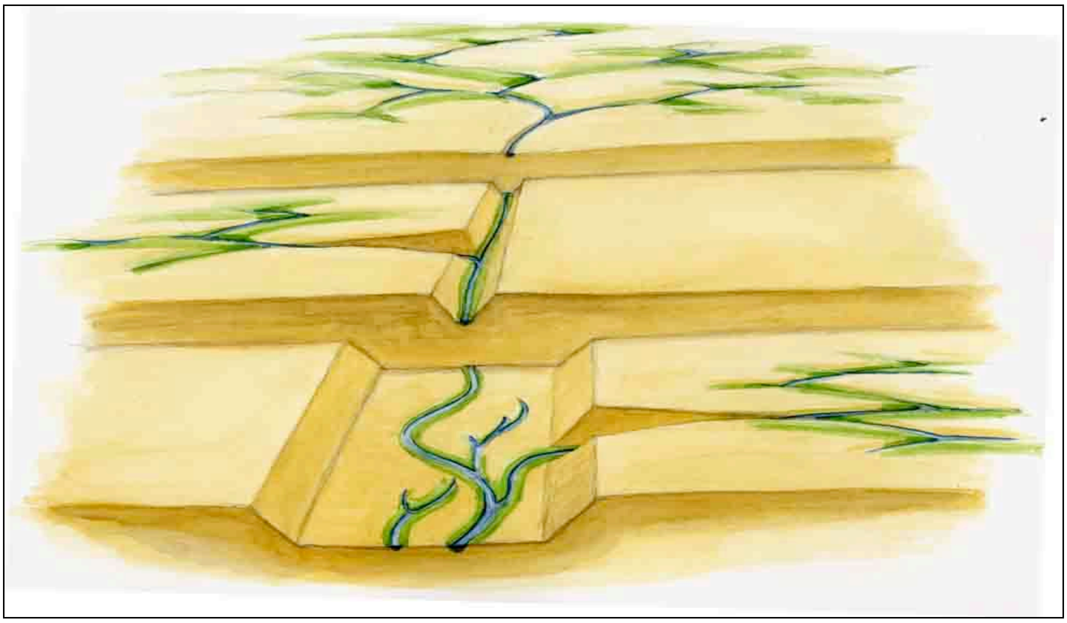


Fig 2.1. Various sections of a river (schematic). The upper parts are the capillaries and have potential for restoration of natural sponges. Ill. Jeroen Helmer.

In this report we are concentrating on the possibilities in the last of these three regions; the possibilities to store and slow down the flow of water in the capillaries of the water system. Before we start doing this however, we will first looking for an answer to another important question: how much water should be held back in these capillaries to obtain a noticeable, meaningful contribution to flooding and drought problems further downstream – be It in the Netherlands or in the lower parts of Germany?

3. What level of storage is needed?

3.1 Flood control and drought control

Water storage can be used to level off flood peaks and to ensure that a certain amount of water can still be released during times with little rainfall. In fact these are two sides of the same coin: if in times of heavy rainfall water can be stored this will level off the peak discharge and be available for release during periods of drought.

Although this is true, there is reason to believe that natural storage will be much more effective as a flood control measure than as a measure for drought control. The reason for this is relatively simple: after heavy rainfalls a flood peak – and thus a potential flood risk - usually will build up within 3-5 days. This means that holding back part of the water during a relatively short period of time will prevent it from contributing to the flood peak. The time between heavy rainfall in winter and spring, and periods of droughts – in particular occurring late summer – is much longer. In order for natural storage to contribute to drought control water therefore would have to be stored for several months.

Because of this we will concentrate on the potential of natural storage for flood control.

3.2 Influencing the build up of a flood peak

In most cases a flood peak builds up after several periods of consecutive (heavy) rainfall. If runoff is fast peaks will be high; if the runoff of water can be slowed down the discharge of the same volume of water will be spread over a longer period of time and hence the peak will be lowered.

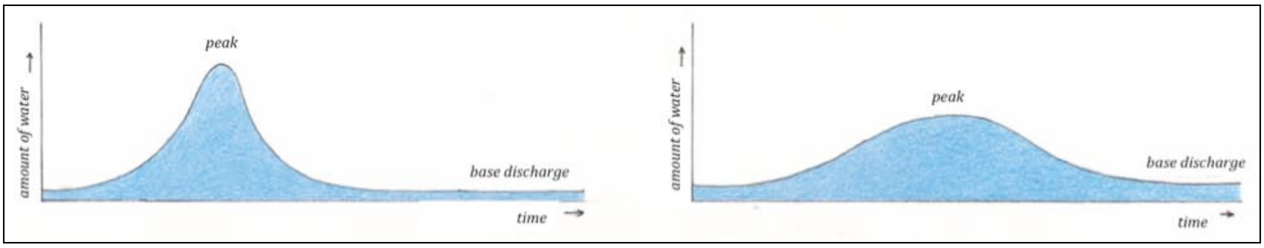


Fig 3.1. The principle of peak level reduction: by spreading the discharge of a given amount of water over a longer period of time peak levels go down.

Analysis of 10 flood peaks shows that on average 15% (between 7% and 18%) of the rainfall in a given period, contributes to the build up of peak. The remaining 85% either is still present in the basin or falls after the peak level already has been reached. This is true for all types of flood peaks: both the normal ones and the peaks reaching or exceeding risks levels (the figure of 18% relates to the year 1993, when critical levels were reached in the river Meuse).

3.3 The challenge

Although an average of 15% of the rainfall in a given period contributes to a peak, it is not necessary to prevent this entire volume this represents from contributing to the peak. What is necessary is to prevent the problematic part of this 15% fraction to reach the river during peak build-up. The "problematic" part is the difference between what the river can safely discharge and the expected maximum discharge or in other words: the maximum peak level that *could* develop and the maximum peak level the river system can safely cope with.

Now let's take the current Dutch situation as an example. After completion of the Space for the River programme in 2015 the Netherlands part of the Rhine basin will be able to safely discharge 16.000 m3/s (Lobith) to the North Sea. Let's also accept that this may not be sufficient and that in fact a discharge of 17.000 m3/s can be expected. This means that 1/17th of the expected discharge must be kept out of the peak, i.e. slightly less than 6%.

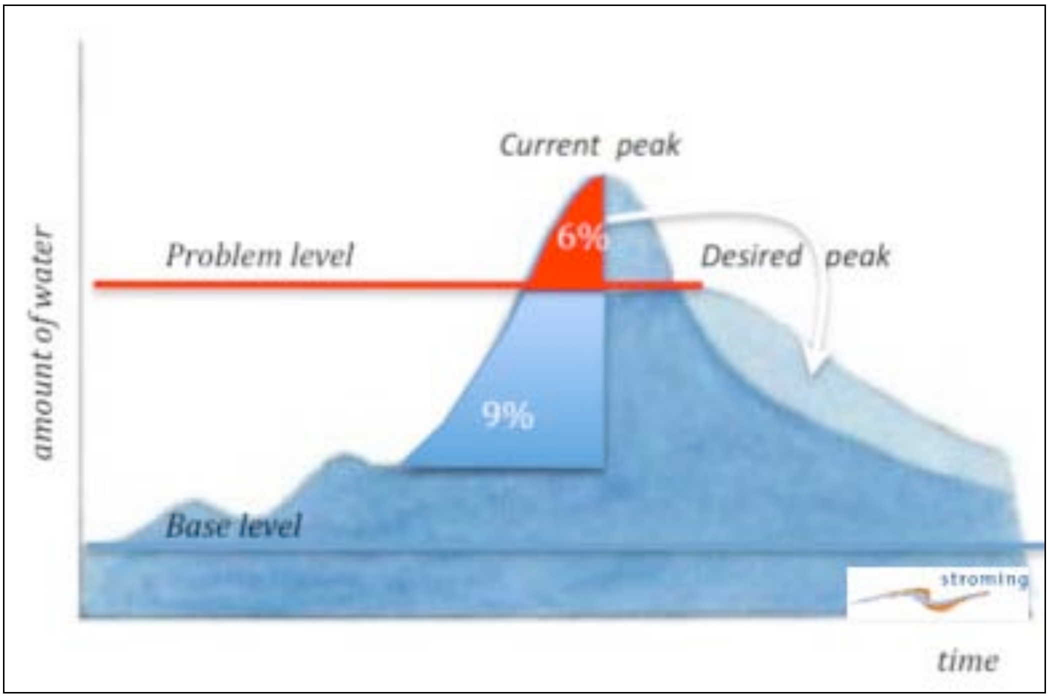


Fig. 3.2. *In a situation without further interventions it is expected that a discharge of 17.000 m3/s could reach the German/Dutch border in future, whereas the Rhine's discharge capacity is 16.000 m3/s. This means that approximately 6% of the precipiation causing the peak discharge of 17.000 m3/s must be delayed for 3-5 days so that it does not reach the river during peak build-up but during the period that water levels are already dropping.*

4. Surface area needed

In order to keep 6% of the precipitation out of the main flow of the river, one would estimate that 6% of the river basin is necessary. There are however three factors influencing this percentage: distribution of rainfall and location.

4.1. Uneven distribution of precipitation decreases area needed

Rainfall in middle mountains is more intense than in other parts of the river basin, i.e. 50% higher. If concentrated in the middle mountains the surface area needed therefore is not 6% but (100/150)*6% = 4%.

4.2 Distance between problem and solution increases the area needed

When a peak travels downstream it sinks in: in as way the "peak problem" reduces itself when travelling downstream. As a consequence restoring natural storage far away from the region where flooding may cause problems, is less effective than when natural storage is revived closer to the problem site. (see fig. 3.3) Preventing 100 m^3/s to contribute to peak build-up in the Ruhr (close to the Netherlands) results in a 70 – 75 m3/s lower discharge at the Dutch/German border. Holding back the same amount of the water from the Kinzig (close to Switzerland) will result in a 40-50 m3/s lower discharge in the Netherlands. In both cases the geographical distance between the problem and the solution causes an efficiency loss. Working from the assumption that measures are taken in the most suitable regions (with 70% efficiency) the area needed for sponge restorationg is not the 4% mentioned in § 4.1 but (100/75)*4% = 5,3%

4.3 Smart location of 'sponges' within regions decreases area needed

Precipitation falling on the plateaus and slopes will travel down and eventually reach the foot of the slope. In a sense the foot of the slope acts as a receptacle for water from the region around it (see fig 3.4.4) . Natural sponges located at the foot of the hill will therefore collect water from a much larger area. An analysis of 5 regions in the Rhine basin (see chapter 5) shows that the surface ratio between 'foot of the hill" and 'slope and plateau' is approximately 1:8. This means that 1 hectare of natural sponge at the foot of a hill collects water from 8 hectares in the direct surrounding. This means that the surface area needed to store 1000 m3/s is not the 5,3% mentioned in § 4.2 but 5,3/8 = 0,66%. Since the Rhine basin measures 185.000 sq km this involves an area of approximately 1225 sq km.

4.4 Sponge capacity decreases over time and this increases area needed

Popular belief has it that at a certain moment, e.g. after continued heavy rainshowers, the natural sponges will be full and stop storing water. This is not the case: there is clear evidence that soils and vegetation are never "full". However: the capacity of soils and vegetation to store water decreases after consecutive periods of (heavy) rainfall. This means that in practice it will be unlikely that the maximum storage capacity can be used when it is needed. It is feasible that there will be situations where – when critical situations start to build up – only 10% of the storage capacity of a given area is still available. On the other hand: it is very unlikely that this unfavourable condition will be found in the entire Rhine basin. For now we will assume, as a worst case scenario that at the start of 'build up' on average 50% of the storage capacity is available in

Rhine basin. This affects the surface area needed: in this 'worst case scenario' we do not need the 0,66% mentioned in 4.3 but twice as much: 1,32% of the Rhine basin (2450 sq km).

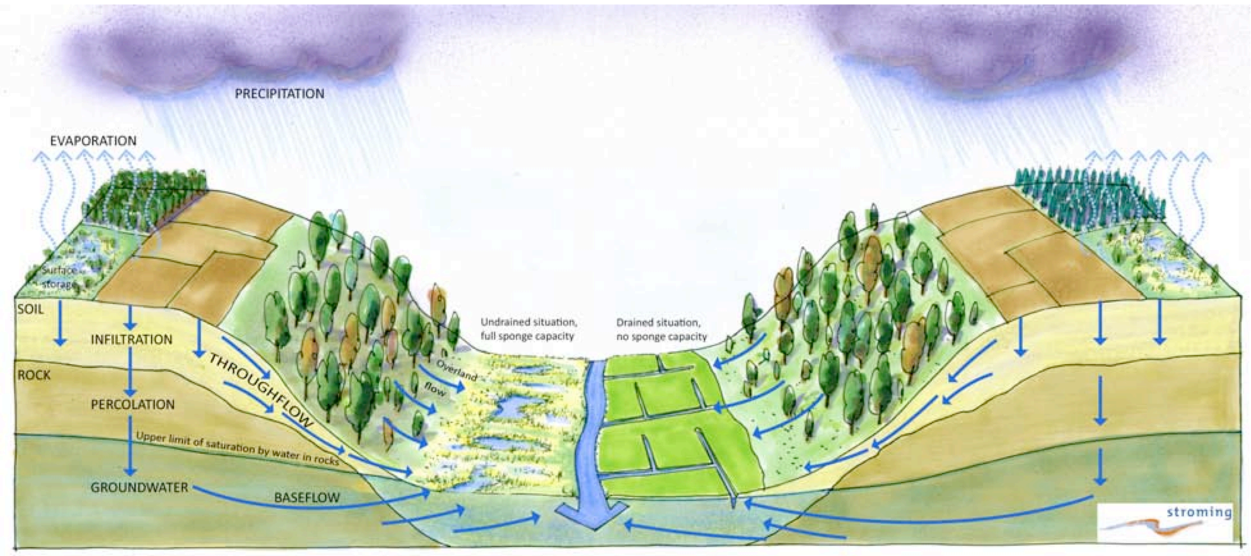


Fig. 4.3. Situation in the middle mountains. On the right the situation which often occurs: the foot of the slope is drained and accelerates the discharge of water from slopes and plateaus. On the drainage was undone, resulting in lower runoff.

5. Surface area available

5.1 Region suitable for natural storage

Areas suitable for natural storage are present widespread in the Rhine basin (see fig. 5.1), especially in the middle mountains. High mountain ranges do not qualify and because most of the precipitation travels downward as overland flow. In addition the big lakes in the Alps act as buffers. This effect is much stronger and overshadows the possible effect of natural storage in the upper parts of the basin. Also low lands and the extensive, flat regions (e.g. the valley of the Upper Rhine) have little potential for natural storage because there are no adjacent higher grounds.

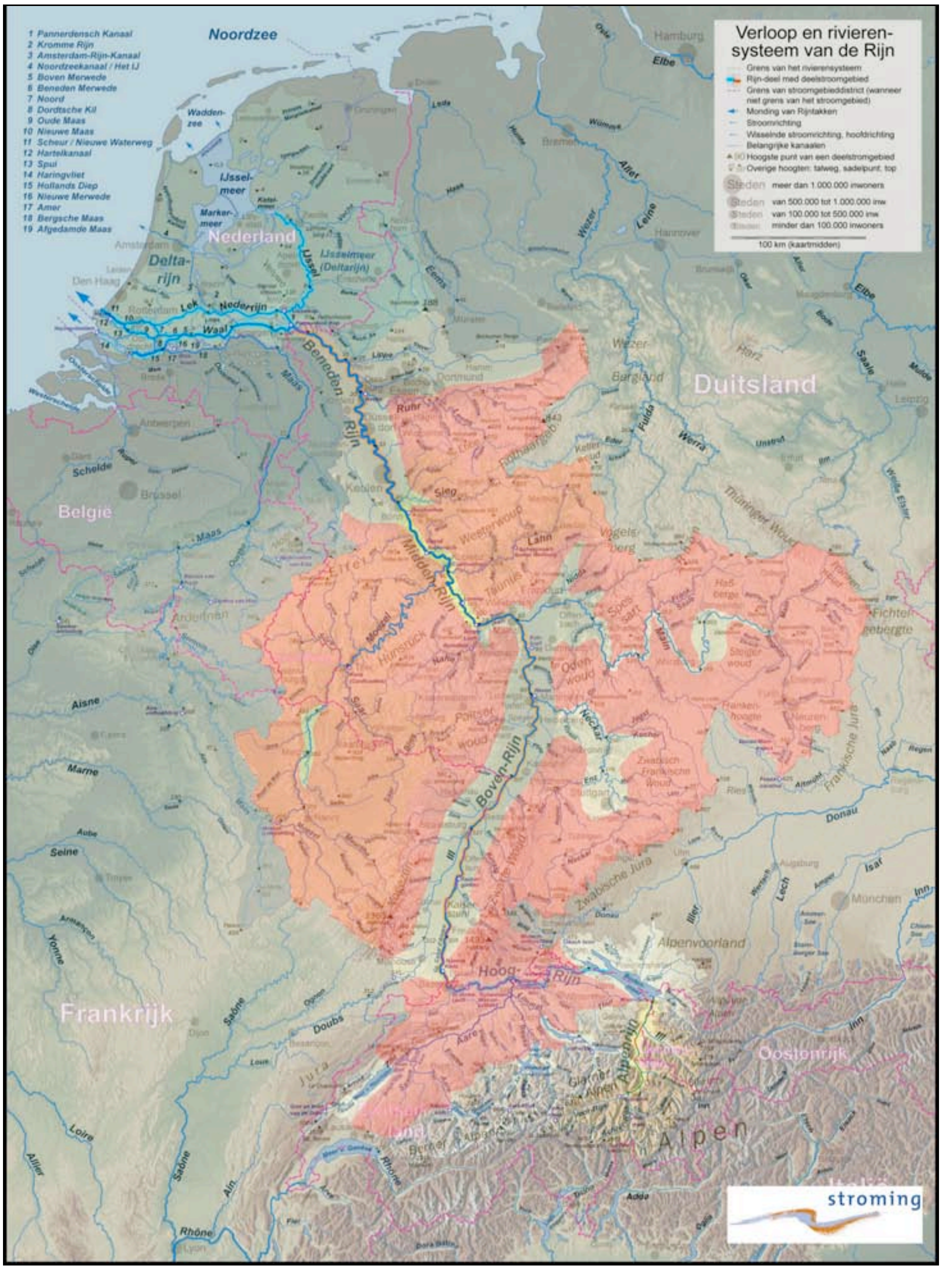


Fig. 5.1 Areas with valleys potentially suitable for restoration of natural sponges. Base map Wikipedia.

Overall approximately 60% of the Rhine basin is suitable for natural storage in the sense that with these 60% areas can be found where water can be held back in the – often broad – valleys before being discharged into the Rhine. Table 5.2 gives an impression of the potential for the most important tributaries. The relative largest potential for natural storage can be found in Glan, Mosel, Lahn, Sieg and Ruhr. Thes are all rivers in the Middle section of the Rhine. In absolute terms the largest contribution is likely to come from the Mosel, followed by the Main and Upper Rhine.

	Surface (sq km)	Percentage suitable	Surface suitable (sq km)	Maximum discharge since 1900
Upper Rhine	54000	40%	21600	4450
Neckar	13900	75%	10425	2750
Main	27300	80%	21840	2150
Glan	4000	95%	3800	870
Moezel	28300	95%	26885	4170
Lahn	6000	95%	5700	840
Sieg	3000	95%	2850	930
Ruhr	4400	95%	4180	910
overig	29100	0%	0	
Totaal	170000		97280	17100

Table 5.2 The most important tributaries of the Rhine and their potential for natural storage.

5.2 Analysis of 5 smaller valleys

A total of 5 valleys (see fig 5.3) were analysed within the framework of this study (Table 5.3). The length of brook valleys suitable for natural storage varies between 230 and 590 meters per kilometre. The mean is 420 meters per kilometre.

	Surface (sub)basin	T=1	T=50	Length suitable	Length/km^2
Wenne	219	48	100	70	0,32
Kyll	301	65	102	145	0,48
Ruwer	102	20	69	60	0,59
Fils	146	20	83	34	0,23
Gutach	145	40	155	70	0,48
Totaal	**913**	**193**	**509**	**379**	**0,42**

Table 5.3. Surface, discharge characteristics, and length suitable for the development of natural sponges for 5 smaller valleys in the Rhine basin. T=1 is a discharge occurring each year, T=50 is a discharge occurring once in 50 years.

They cover slightly less than 1% of total area suitable for natural storage. Assuming that these valleys are a fair reflection of the situation in the Rhine basin the total length of valley suitable for natural storage would amount to 40,000 km.

Fig. 5.3. Location of the 5 valleys examined in terms of their potential for natural storage. The 5 valleys are spread throughout the Rhine basin in order to include regional differences and obtain a more or less representative sample. Base map Wikipedia.

5.3 Contribution to the peak reduction on the Rhine.

In the Netherlands the Rhine basin is considered “safe” if it is able to cope with a discharge occurring once ever 1250 years. However, a T=1250 situation will never occur at the same time in all parts of the Rhine basin. In fact, a T=1250 situation in the Netherlands and lower parts of Germany will build up in the theoretical situation that a T=50 discharge takes place at the same time in large parts of the Rhine basin. In other words: a T=50 discharge in large sections of the middle mountains, will translate itself in a T=1250 situation (even worse) In the lower parts of the Rhine basin. During a T=50 occurrence the 5 valleys included in this research generate a combined discharge of approximately 500 m3/s.

If the maximum discharge of all tributaries combined, would result in a total discharge of approximately 17,000 m^3/s (table 5.2) in the downstream parts of Germany and Netherlands. In reality the maximum discharge (Lobith) was never higher than 12,600 m^3/s. There are two reasons for this. First, the peak of the tributaries will never coincide with the peak in the mainstream. Second, a flood peak in the main stream will gradually collapse when travelling downstream by 25%. This also means that, in order to decrease a flood peak at the Dutch/German border with 1000 m3/s, a 25% higher amount of water (1250 m^3/s) must be stored higher upstream.

If the total length of 40,000 km of suitable valley could be used to store a discharge of 1250 m^3/s, and if in those valleys a zone of (on average) 50 meters would be available, this would result in a sponge area of 2000 sq km. This is close to the outcome of the rough estimate of the area needed (see 4.4).

6. Costs

What would be the costs of a strategy based on the restoration of natural storage? There are several answers an within the framework of this brief report we will explore two of them.

5.1. Purchase of land

One possibility is to purchase land for water storage. Depending on the region and taking into account where possibilities exist (fig. 3.3) prices per ha vary (2012) amount to approximately € 12.000 per hectare (fig 5.1).

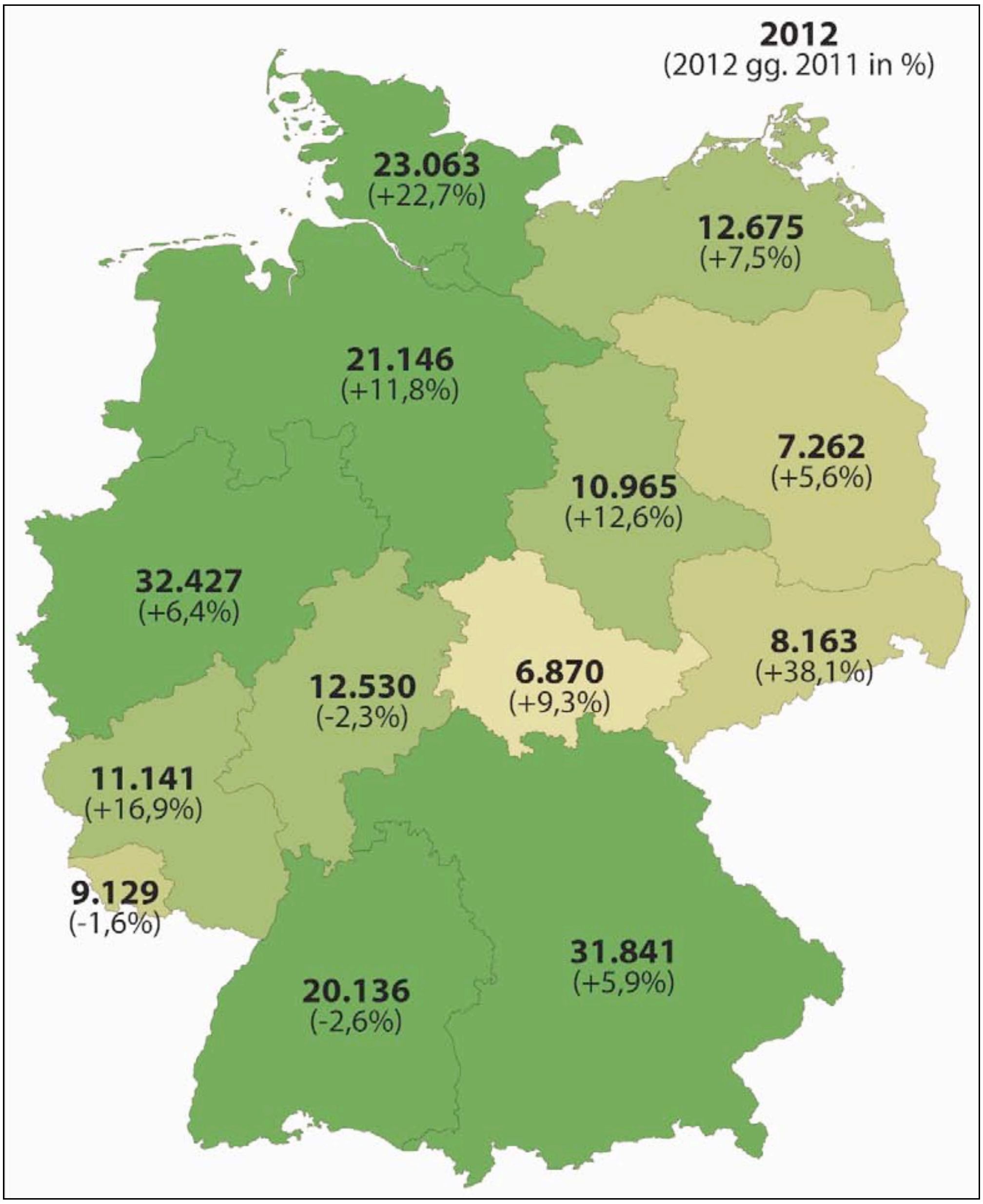


Fig 5.1 Land prices in Germany vary between Bundesländer (and development against prices in 2011). Source AMI.

The purchase of 2450 sq km (245,000 ha) would require € 2,94 billion. This is at the lower end of the cost estimate for the next round of river safety measures included in the Deltaprogramme. It should be borne in mind that:

- the lower estimate (€ 2,5 billion) relates to monofunctional measures only
- the higher estimate (€ 7 billion) relates to a multifunctional approach
- up till 2021 Germany wil invest € 5,7 billion in river safety, incuding 2,8 billion for retention polders.

5.2 Compensation per m^3 stored

Land purchase is not the only possible strategy to implement a restoration strategy. It is also possible to provide landowners with a “storage fee”.

If an amount of € 3 million would be used and if one would assume an interest rate of 3%, this would be allow for a total annual storage fee of € 90 million i.e. € 350 per hectare.

Annex I Context and scope for this quick scan

1. Background

Green Rhine Corridor is a broad, international coalition aiming to develop the Rhine as an ecological and economic backbone of Europe. The partners and supporters share common targets on:

1. Longitudinal connectivity: primarily fish migration.
   Migratory fishshould once again be able to migrate freely up and down the river.
2. Lateral connectivity: Room for the Rhine.
   A Room for the River approach should be fully embraced for the whole river basin.

These targets can only be achieved in international cooperation among NGO's and with governments, businesses and other relevant players. Non-conservation partners have been (successfully) invited to join Green Rhine Corridor and others may follow. Green Rhine Corridor is not "ready" but "ready to go". Initial work focused primarily on salmon and on ICPR and its Ministers Conference of 28 October 2013. The initiators of Green Rhine Corridor propose to continue the cooperation and revamp Green Rhine Corridor as a 3-year program, with concrete activities and external (e.g. EU) funding.

2. Cost- benefit analysis of a Room for the River approach

The vision of the Rhinecorridor network is that a Room for River approach applied all along the river is benificial for the economy ánd the ecology of the Rhine basin.
One issue that may well be less expensive to solve when thinking on a river-scale instead of locally is the control of floods and droughts. The river Rhine is shorter and narrower than it was before: meanders were cut off and dikes narrow down the winter bed. ICPR states that the Rhine lost 85% of its original flood plain. As a consequence water travels faster downstream than ever before, causing higher flood peaks and longer periods of drought. Not all developments should be turned back, but some of them can. Rivers can be granted more access to floodplains, thus increasing the rivers capacity and lowering flood peaks. The target should be to at the same time also restore the marshes in the middle mountains which feed the tributaries to the Rhine. Almost all of them were drained and developed as agricultural lands. Modern farming however is not economically feasible in these remote and sloping areas and many lands have been abandoned in recent years.
Restoring access to floodplains and restoring marshes in the middle mountains would help to store water during times of plenty rainfall, thus reducing flood peaks and securing a prolonged supply of water during droughts.
Profitability: The potential is high. In the Netherlands alone € 1,9 billion was spent to prepare the Rhine to accommodate an expected extra 1000 m3/s: a financial injection of € 6 million per km. Channelling part of this money to integrated solutions (incl. further upstream), i.e. linking flood control to habitat restoration, is a major opportunity for restoration of riverine habitats. Reducing flood peaks and droughts will not only bring profits for water managers, but for all those who are faced with the impact of regular high waters and droughts like those who live and work in areas with regular inundations as well as those who are dependent from the river. Like for transport or the withdrawel of water (drinking water for civilians, processing and cooling water for the industry, irrigation water for agriculture) etc. Normally the costs

and benefits of different scenario's for water management are not calculated, the decision making is a political process with little interference of other stakeholders. Rhinecorridor partners are in favour of a more transparant process, based on the comparison of different scenario's with calculations of the costs and benefits for different stakeholders. It is convinced that such an integrated approach will bring more benefits for the economy and ecology than the current approach which mainly focusses on water safety and water quality within strict boundaries. Rhinecorridor wants to demonstrate the added value of such an integrated approach by calculating the costs and benefits of a defined measure that is not yet on the agenda of the Rhinecommission, namely the costs and benefits of restoring sponges in the middle-mountains.

3 Goal of the co-operation under the MoU

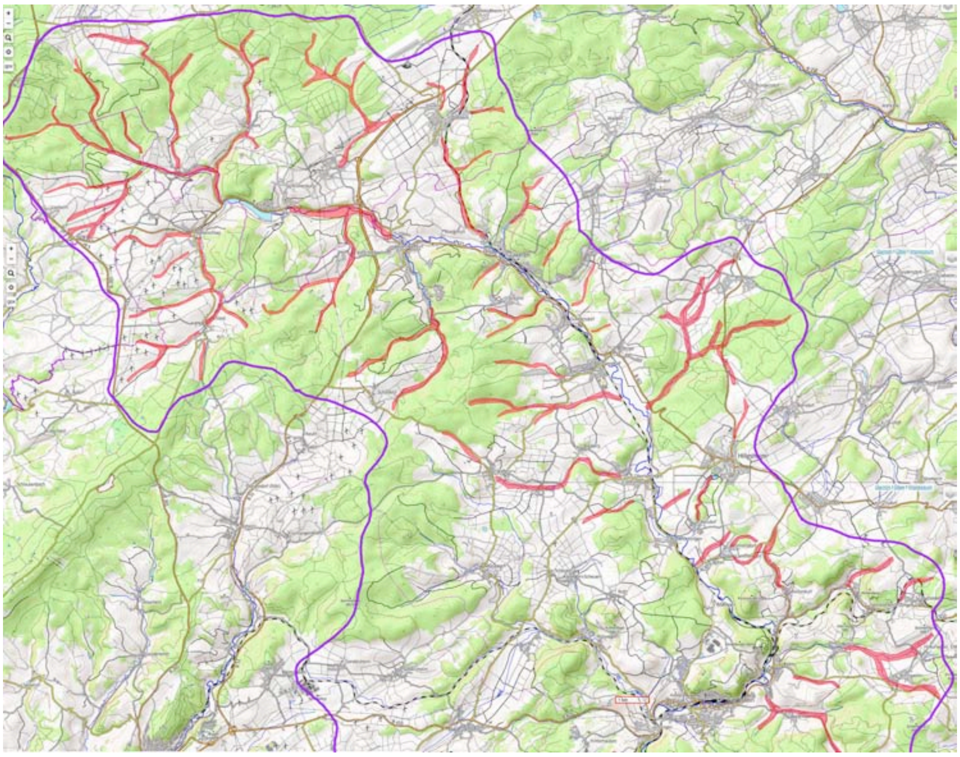
The MoU Partners agree to take the first steps towards a cost-benefit analysis as described under 3 as a common effort. The results will be presented to the Rhinecorridor partners for approval and can serve as a basis for a more comprehensive analysis to be submitted for external funding by the Rhinecorridor coalition member responsible for this topic, Erik van Zadelhoff (Platform BEE).

5 Approach

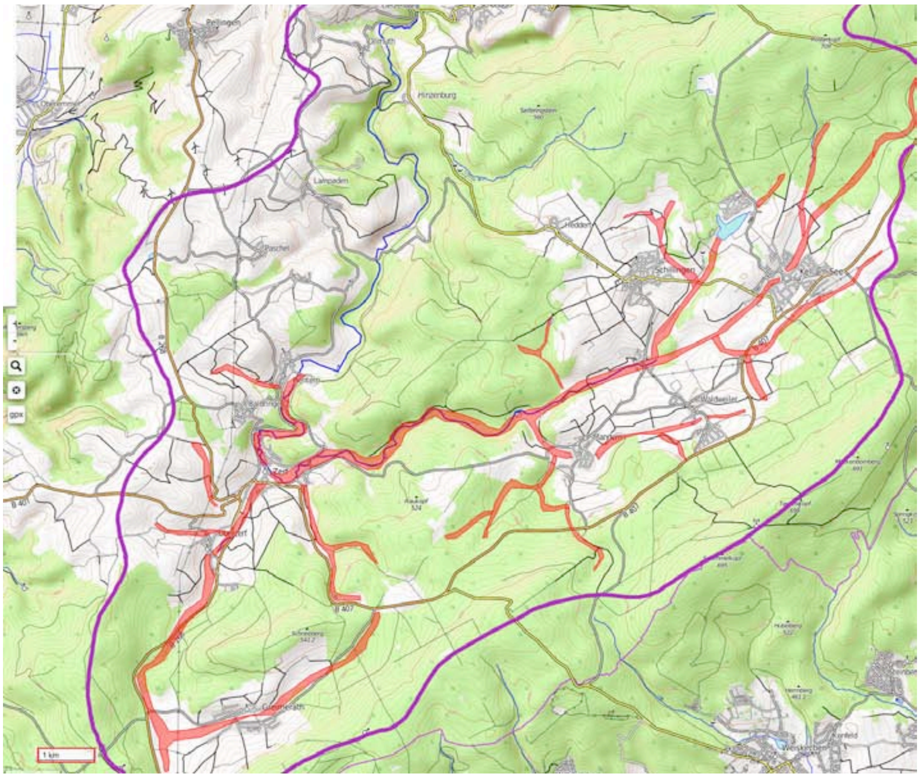
The MoU Patrners agree to follow a phased approach, consisting of the following steps.

1. A brief analysis of the current status of cost benefit analyzes within or related to the current Rhine Action Program (including scenario studies), resulting in a report with an evaluation of the program in this respect.
2. An overview of cost-benefit analyzes in river management (report + powerpoint presentation)
3. A 'best guess' of the effectiveness of sponges in terms of lower peaks and less droughts in the River basin of the Rhine in the shape of a brief report with explanation of the assumptions.
4. A stakeholder analysis; which partners would profit most from lowering peaks as a result of restoring sponges and might become strong allies (for instance cities, harbours, but possibly also private companies) and which might be willing to join Rhinecorridor in commisioning step. Also this should result in a report.
5. An elaborated ToR for a comprehensive cost-benefit analyzes based on the first four steps
6. Granting a contract for a comprehensive analysis

Annex II Analysis of 5 valleys

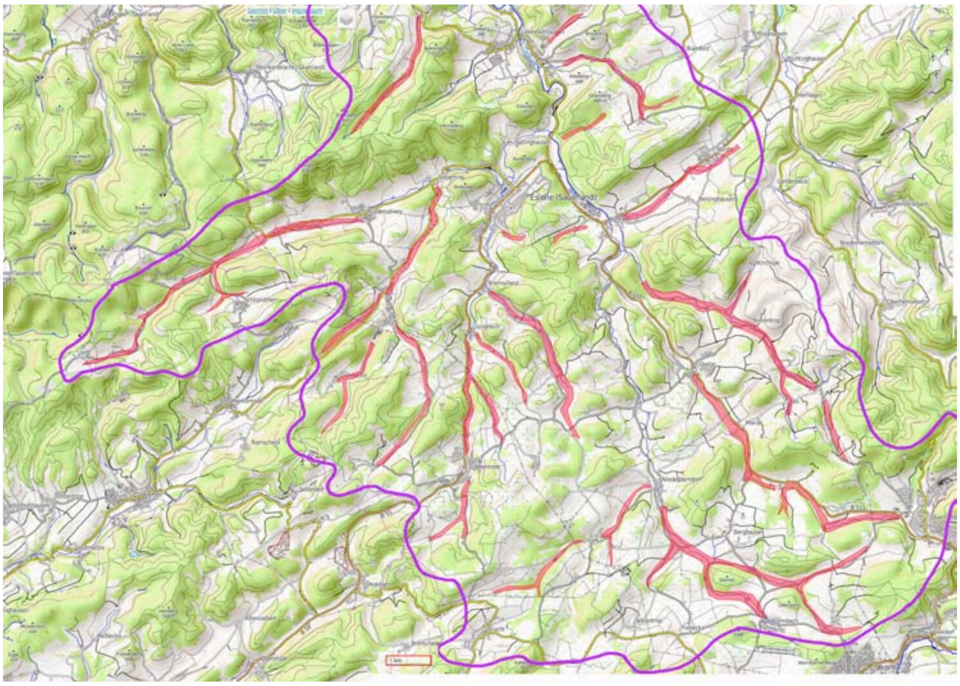


Suitable valleys in the upstream part of the Kyll.

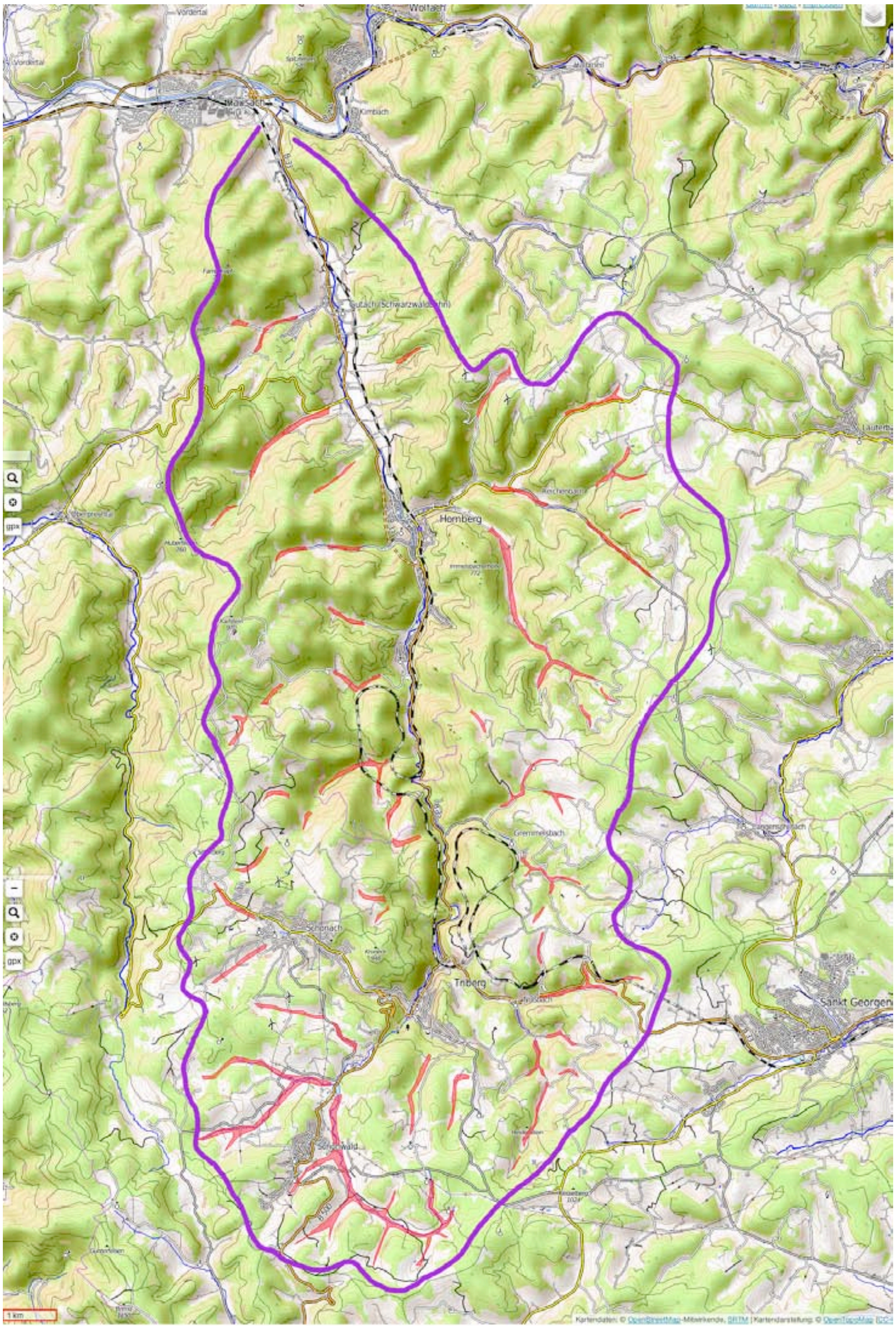


Suitable valleys in the upstream part of the Ruwer.

Suitable valleys in the upstream part of the Fils.



Suitable valleys in the upstream part of the Wenne.



Suitable valleys in the upstream part of the Gutach