Explorationphase renaturing river Worm

Subtitle - Design outlet Anselderbeek at Rimburg

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EMFloodResilience

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1 Introduction

1.1 Reason and Purpose

This design note 'Exploration phase renaturing river Worm' is part of the redevelopment plan for the border stream the Worm at the section RWZI Rimburg and the Wolfsweg Eygelshoven. The main objective of the redevelopment is to improve the ecological situation in order to achieve the WFD (Water Framework Directive) objectives. Partly due to canalization in the 1970s, the ecological quality of the stream has declined significantly and in the present day the stream does not meet the WFD objectives for "Other Aquatic Flora". In the assessment of the entire water body, the parameters Macrofauna and Fish score sufficiently, but there is still room for considerable improvement in specific sections. The examined redesign measures focus on a more natural arrangement of the stream, the removal of unnatural bed stream constructions and the creation of more space and variety of habitat (i.e. by meandering the stream).

1.2 Project area

The Worm is a fast-flowing, meandering hills land stream located largely on the German territory. The Worm has a surface area that covers a total of 356 km2 of land and partly overlaps with the Maas. The Worm originates from the German Aachener Wald,south of Aachen, and flows into the Roer north of Heinsberg. In between, the stream flows through the German municipalities of Würselen, Herzogenrath, Übach-Palenberg, Geilenkirchen and Heinsberg and the Dutch municipalities of Kerkrade and Landgraaf. The basic discharge of the Worm consists largely of effluent from several sewage treatment plants in Aachen. For a trajectory of several kilometres, between Haanrade and Rimburg, the Worm lies on the national border between the Dutch province of Limburg and the German state of North Rhine-Westphalia. Waterschap Limburg manages this border-crossing section of the stream. In the 1970s, the Worm was canalized for the trajectory starting from the NATO depot Eygelshoven to beyond the border near Rimburg, as a result of which its ecological value has greatly diminished. This forms the project area for the redevelopment (see Figure 1.1).

In the northern part of the project area, the is stream channelized with boulders and surrounded by urban and agricultural areas. There is an original meander on the north side of the NATO depot, after which the stream slowly changes further south to a gently meandering stream with woody vegetation on either side.

Figure 1.1 Project area (red line), map and picture impressions.

1.3 Leader

This design note provides an elaboration of the redevelopment design. This document explains and records the process steps and choices made in the exploration phase to come to an outline design. The design note forms the starting point for the next phase and the plan execution phase, in which the further detailing and (dimensional) incorporation of the various components are key. Establishing the choices from the exploratory phase provides all parties involved with a degree of certainty and clarity about how the objects will be adapted.

Chapter 2 explains the project scope. Chapter 3 describes an analysis of the (water) system and its opportunities and bottlenecks. Chapter 4 explains the design vision and elaboration, including a variant description and consideration. In chapter 5, the chosen variant is further detailed, explained and tested with a hydrological model calculation, after which advice is given on optimisation of the design for the planning phase.

2 Project scope

2.1 Objectives

1. **Complying with ecological objective of WFD**
   The Worm must meet the WFD objectives in 2027. For the parameter 'Other Aquatic Flora' in particular, the current status in the Worm does not meet the targets, which means that the target range for 2027 is uncertain (Worm Fact Sheet, Water Quality Portal 2021). In particular, the sub measurements aquatic flora floating and aquatic flora emergent score insufficiently over the entire Worm. The sub measurement aquatic flora submersed scores insufficiently in the southern part. Within the project area, uniform water depth and current velocity, unnatural morphology and limited shading can be seen. All factors that negatively affect the achievement of the targets and can be improved with design measures.
   The effluent from several German sewage plants above the project area largely determines the base outflow of the Worm. As part of the WFD, Germany is committed to measures that ensure improved water quality of this effluent. This also contributes to improving the target reach of the Worm in the project area.

2. **Striving for system restoration**
   The Worm should be set up as a nature stream where there is an eco-hydrologically healthy functioning water system and where interaction with the surrounding area has been restored.

3. **Meeting the NBW standards (climate-robust)**
   The Worm should be designed so that the level of flood protection meets at least the NBW standards and deterioration of the situation for the functions present is prevented.

2.2 Prospect

The prospect for the Worm is a water system where the stream (zone 1, see Figure 2.1) has a variation in flow velocities, water depth and bottom substrate (including gravel in different diameters). The stream course varies widely in width and depth, both longitudinally and transversely. At the sharper meanders, steep walls are present in outer curves and banks with coarse sand or gravel are present in the inner curves. There is a strong interaction between the vegetation on the banks and the morphology in the stream system. Dead wood is present in the stream in many places. In addition, there is an attached transition zone with root assemblages in the water. Here, spontaneous development of softwood alluvial forests is encouraged in alternation with open wetland lowlands and pools.

Along a larger length along the Worm, a forest zone will develop, alternating with open wetland areas. On the wettest areas, alder thickets will occur and on the less wet areas, bird catcher woodland will appear (zone 2). Where there is enough space, a woodland scrub zone (zone 3) can develop with a gradual overflow to the buffer zone (4) with flower-rich grasslands (glossy oat and foxtail hay meadows, or, if this is not feasible, herb- and fauna-rich grasslands with rough grazing).

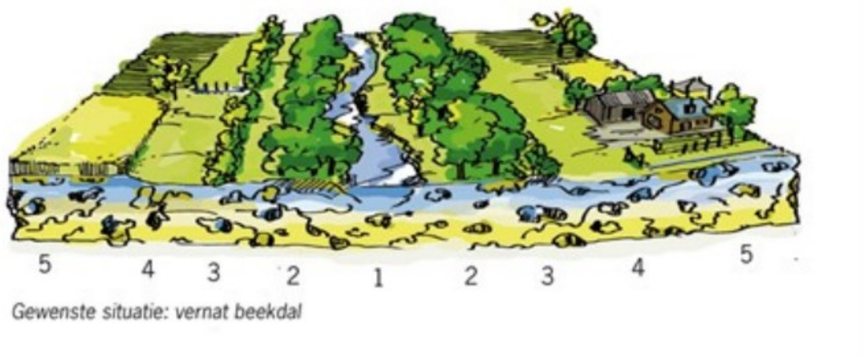

Figure 2.1 Prospect valley design: Function and purpose of different stream valley zones as described in (Verdonschot, The wide stream valley as a climate-resilient buffer in the changing habitat (Verdonschot, The wide stream valley as a climate-resilient buffer in the changing living environment, 2019.

2.3 Guiding principles

The following principles form the basis for achieving the objectives and working towards its prospect.

2.3.1 Bottom substrate and riverbank structures

The presence of the following substrates and structures is desirable to foster the presence and diversity of aquatic flora, macrofauna, fish and other species:

- Leaf deposits, wood structures and root bundles in the riverbank.
- Presence of gravel beds of different diameters
- Presence of silt and detritus beds
- Presence of dead wood

Besides applying direct measures such as gravel substrate or adding dead wood, creating variation in flow velocity and water depth works through varied bottom substrate and riverbank structure.

2.3.2 Hydrology

Flow

For both the aquatic water flora and macrofauna, it is important to create a wide variety of habitat availability in the stream. Variation in flow velocity is an important factor for this. In particular, lateral variation in flow velocity (perpendicular to the stream course) is conducive to the establishment of aquatic plants and macrofauna and because it allows for differences in substrate.

It is important that the flow velocity over the entire length does not become too high. Flow velocities that are too high hinder the migration of fish species and cause undesirable runoff. In the current situation, there are 13 bed traps that, to a certain extent, are considered to be fish migration barriers: locations in the stream where flow velocity in particular is limiting for migration of desired fish species in the stream (see also Exploration Worm Ecological System Analysis and Target Image WAB019165-D-006, Version 6.0 WSP 10 Jan 2023). Table 2.1 shows the desired species with their desired and maximum flow rates, which will be taken into consideration in the design. .

With the redesign of the Worm, extra habitat can be created for species that now mainly inhabit the Rur (including brown lamprey, grayling and brown trout) and can migrate to the Worm. In order for these species to actually reach and colonize the planned area, the downstream habitat should also be optimized for this purpose. However, this task is beyond the scope of the project.

Water depth

In conjunction with variation in flow velocity and variation in bottom substrate, more variation in water depth should be created in the new situation. Here, it is desirable that shallows (with gravel deposits) are created and that the stream does not run completely dry and maintains a flowing section of at least 20 cm deep.

Table 2.1 shows the target water depth for the various potential fish species. The conclusion is that a depth of at least 40 cm should be realized to facilitate these species.

Table 2.1 Desired and maximum flow rate & target water depth for potential fish species in the Worm.

FISH	DESIRED FLOW RATE (M/S)	MAXIMUM FLOW RATE (M/S)	TARGET WATERDEPTH
ELRITS	0,05 – 0,3	0,9	> 25 cm
BEEKDONDERPAD	0,1 – 0,3	0,4	10 - 100 cm
VLAGZALM	0,4 – 0,7	0,7	30 - 60 cm
BEEKPRIK	0,3 – 0,6	1	40 - 100 cm
BEEKFOREL	02 – 0,8	0,8	30 cm

Flooding norms

The valley of the Worm consists largely of areas with no regional flooding norm (Figure 2.2). The NATO site has a flooding norm of 1:100 but this site is more than 6 meters higher than the surrounding sites. The village of Rimburg has a standard norm of 1:100 and a number of areas with a standard of 1:25 and 1:10. The guiding principle is that inundation may not increase compared to the current situation.

For the German side the design should be tested everywhere with the 1:100 situation, with the assumption that inundation may not increase compared to the current situation. In addition, any loss of storage must be compensated for.

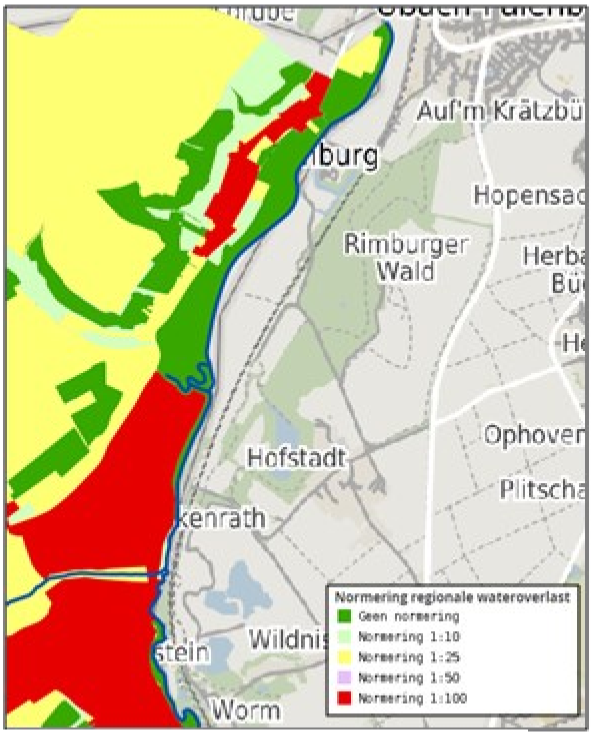

Figure 2.2 Existing NBW Norms

2.3.3 Maintenance

The renaturing aims at a practical maintenance-free water system, based on a dynamic natural balance in the river zone. Excessive erosion must be prevented as much as possible in a natural way, preferably with natural materials or the reuse of materials (boulders) from the existing layout.

The stream must also be accessible on both sides of the border for management and maintenance by paths of 4 meters wide.

2.3.4 Land Acquisition

In essence, efforts should be made to utilize the lands already owned by Waterschap Limburg and the German Wasserverband Eifel Rur (WVER) as much as possible. However, the current course, on Dutch territory, is (largely) situated on the property of the municipality of Landgraaf. It is desirable to acquire these lands. Subsequently, it is preferable to find any necessary space on lands owned by other government agencies. Optionally, possibilities for acquiring private properties may also be explored (only through amicable land acquisition).

Land acquisition is also being explored on the German side. To this end, Water Board Limburg, WVER and the Municipality of Übach-Palenberg are acting jointly in discussions with landowners.

2.3.5 Recreation

The primary function of the Worm is a natural stream. Recreational co-use can be facilitated by opening the maintenance paths for hikers, on condition that this does not infringe on existing privacy. The water board is open to other initiatives, on condition that this does not interfere with its own objectives and that financing is guaranteed.

2.4 Commonalities

2.4.1 Natura2000

The German part of the plan area from the Kraangracht to the south, is part of the German Natura 2000 area 'Wurmtal nördlich Herzogenrath'. This nature reserve covers an area of 18,84 ha and has the following protected habitat types: Streams and rivers with aquatic plants (H3260), shining oat and foxtail hay meadows (H6510), Valley forests, alder thickets and softwood riparian forests (91E0).

The objectives are (http://natura2000-meldedok.naturschutzinformationen.nrw.de):

- Restore natural flowing water with submerged vegetation with characteristic riverbank structures and habitat characteristic species and structural diversity as well as river dynamics.
- Restoration of nearly natural water structure at least with classification of water structure '3' (moderately altered) to one that is as untouched as possible.
- Restoration of habitat types with typical characteristics (discharge behavior, soil load balance, river dynamics, connection of tributaries and floodplains as habitat for its characteristic species).
- Restore high water quality with maximum moderate organic loading.
- Avoid and if necessary, reduce inputs of nutrients and pollutants.
- Restoration of undisturbed habitat.

The redevelopment measures should be consistent with these targets, especially in the restoration of naturally flowing water and natural water structure.

2.4.2 Water in Balans Projects

Waterschap Limburg works through the WaterinBalans (WiB) program to reduce the risk of flooding in the south of Limburg. The planning areas of the WiB projects Rimburg and Eygelshoven are part of the Worm rivervalley. Excessive rainwater floods from these areas through a few side streams, but mostly also through surface runoff towards the Worm. The WiB projects investigate whether water can be retained upstream and stored longer and whether the runoff towards the Worm can be improved without causing transfer. The interface of these projects will be coordinated for the redevelopment and the connections must be incorporated in the design.

2.4.2 German Masterplan Worm

The project area of the renaturing of the Worm interfaces with the search area for flood protection measures for the Master Plan Worm by the German WVER. Within the framework of a European Interreg grant, together with the German stakeholders, it is being investigated whether incorporation of flood facilities in the planning area is efficient to reduce flooding in the entire surface area and in particular to protect urban areas with a standard of 1:100.

2.5 Participation

During the planning process, the community has been involved in several ways. During a residents' meeting on June 7, 2022, the objectives of the study were explained, and broad local knowledge and ideas were collected. During a second meeting on March 31, 2023, various variants were explained, and residents and other stakeholders were able to contribute ideas about further elaboration of the scenarios. In parallel, individual discussions were held with the various government organizations involved, both in the Netherlands and in Germany.

Frequent consultations are held with the Wasserverband Eifel-Rur about the developments in the project and their wishes, principles and ideas regarding the (re)design tasks. The intention is to conclude the exploration phase with a cooperation agreement between Waterschap Limburg and the Wasserverband Eifel-Rur.

2.6 Risk dossier

Two risk sessions were held during the project. The results of these sessions were recorded in a risk file and embedded in the designs and process. This resulted in the following top risks for the project, with several risks already controlled or discounted in the estimation of the variants:

- Occurrence of archaeological (accidental) finds
- Occurrence of protected plant or animal species
- Detection of explosive remnants of war
- Land acquisition is not feasible
- Risk of excessive management and maintenance effort
- Permeability

2.7 Sustainability

Using the ambition web and the environment guide (tools of Sustainable GWW), two sessions were held to identify ambitions and opportunities in the area of sustainability.

2.7.1 Ambition session

In the initial phase of the project, the ambition levels per sustainability theme were determined in a collaborative brainstorming session with the water board. The sustainability objectives, as included in the Sustainable Together Policy Document (WL & WBL, 2020), were considered as the basis for this. In addition, the following ambitions were formulated for the project.

- Ecology
  Within the project, the aim is to broadly restore the biodiversity and ecological structures of the stream system. Restoring natural hydromorphological processes is an important starting point. In addition to achieving the WFD goals within the stream course, efforts are being made to achieve a robust stream valley-wide improvement.
- Water
  The stream restoration measures and the achievement of the WFD objectives contribute to improving water quality. It is essential to prevent contamination from mine tailings due to adjustments in the streambed. Additionally, possibilities are being explored to store water and delay peak discharges. The implementation of flood safety measures is also being considered in coordination with German partners.
- Energy
  The ambitions within the project focus primarily on limiting energy consumption and CO2 emissions during the construction and management phases by deploying low-energy equipment, using renewable energy/emission-free work and limiting the use of equipment and materials.

Any energy generation measures should not conflict with the primary function as a nature stream.

- Materials
  The project aims to reuse materials within the area: soil, rock, wood. In addition, the ambition is to only use materials that can be reused.
- Spatial quality
  The redevelopment measures can contribute to improving the landscape quality in the area.The (recreational) experiential value is subordinate to the nature objectives.
- Soil
  The goal is to affect the soil system as little as possible and to preserve existing qualities (such as the archaeological soil archive) as much as possible, for example by searching for historical meanders.

2.7.2 Environment session

On May 19, 2023, an environment session was organized at the Eurode Business Center in Herzogenrath with both the Dutch and German authorities involved. The purpose of the session was twofold. On the one hand, it was about identifying opportunities and possibilities within the themes of the Omgevingswijzer. On the other hand, the aim was to develop mutual understanding and learn from each other. The focus was on understanding how sustainability is integrated into both Dutch and German projects."

During this session, the parties interacted, and ideas and expectations were exchanged. For example, the German water board can contribute ideas about the efficiency of flooding facilities in the planning area and this cross-border theme may also contribute to the willingness of German landowners to make land available for the redevelopment project. On the Dutch side, the municipality may be able to contribute by establishing a wide buffer and/or meander zone on their municipal (leased) land with more room for natural processes and less intensive agriculture.

What we learned from each other is that on the Dutch side, sustainability and the themes of the Omgevingswijzer are approached very explicitly. The projects on the German side consider sustainability more implicitly and more pragmatic (where can it help our project). There is something to be said for both approaches. For the small-scale stream restoration projects, the outcome seems to be similar for both approaches. For the larger infrastructure projects, an explicit approach seems likely to offer benefits.

3 System analysis and its opportunities and bottlenecks

The following chapters considered the ecohydrologic functioning of the Worm as a system and elaborated on the current and potential natural values and associated opportunities and constraints. This chapter is an excerpt from the full system analysis as described in the document WSP-WAB019165-D-006-Ecological System Analysis and Target Image-v6 (not included).

3.1 Ecology

3.1.1 Prospect

Flora
When obtaining a more natural substrate, variations in flow velocities, and space for dynamic processes such as erosion and sedimentation, a logical consequence is that the coverage of submersed and emergent vegetation can develop more effectively. This will be localized, as vegetation in the midstream of a stream naturally occurs with limited coverage (5-20% of the water body).

Referring to the upstream part near Haanrade, a realistic risk is that even with a more natural design, the riparian vegetation may still be dominated by species such as the Large Stinging Nettle, Japanese Knotweed, and Himalayan Balsam. In fact, during vegetation excavation, Himalayan Balsam may potentially gain an advantage in establishment. As an annual plant, it requires open spaces or disturbances each year to germinate. This is limited in the current situation by dense vegetation of the large stinging nettle.

To prevent this, it is necessary to consider solutions to prevent dominant establishment by nettles and the invasion of exotic species. For example, by spreading vegetation cuttings from a reference bank onto a newly designed location, allowing the seeds of desired species to establish more rapidly and thereby gaining a slight advantage over invasive exotics. This can be beneficial, for instance, in limiting the dominance of Himalayan Balsam. In addition, it is necessary to control outbreaks on the project site (and upstream), to the extent possible.

Macrofauna
According to the WFD theme, the Worm scores 'good' in the macrofauna species group. Nevertheless, there is much that can be done to enhance the habitat for macrofauna. The presence of shrubs and trees provides habitat for caddisflies (adult case-bearing caddisfly Lepidostoma basale), and a potentially suitable understory for the large water cricket (Aquarius najas) to overwinter.

In addition to the species already present, one-day fly species Baetis liebenau, Heptagenia flava, Paraleptophlebia submarginata and Ecdyonurus dispar would occur in the future situation. The tubeworm species Lepidostoma hirtum and Lepidostoma basale, dependent on wood in the stream, also occur. The beetle species Potamantus suteus and Esolus parallelepipidus are also found in the Worm. The now absent stoneflies are represented again with the species Perlodes microcephala and the genus Leuctra. The River Clubtail can also be found again in addition to the current dragonfly fauna. This can be achieved by returning gravel of different diameters to the new situation. Variation in fast-flowing and slow-flowing sections is important here. This variation can be achieved by providing more space for the Worm with lots of stream-guiding woody vegetation, and with tree roots also present in the water column. In contrast to the Common Clubtail and Small Pincertail, the River Clubtail prefers not only woody vegetation but also some openness in the landscape. In addition to the River Clubtail, several species depend on a locally semi-open landscape.

Species such as Beautiful Demoiselle, Common Clubtail and the Small Pincertail, can reach the plan area from downstream and upstream areas, provided suitable habitat is available. A small population of the Small Pincertail is already located several 100s of meters upstream. The Common Clubtail has been observed here occasionally, but to what extent this species actually occurs here is unknown. In addition to breeding water, terrestrial habitat is important for adults to hunt. This takes the form of forest edges and wooded banks.

Species such as White-letter Hairstreak and Small Skipper occur in the region and may colonize the area from there. The White-letter Hairstreak is highly dependent on elms, the host plant. Prerequisites are that elms are present in favorable locations, preferably in close proximity to nectar facilities for the imago in the form of flower-rich grasslands. The Small Skipper lives in rough grasslands and in forests and marshes with sufficient herb-rich vegetation. The condition is the presence of overgrown grasses with fallen leaves in the autumn, where the specie lays its eggs. Suitable habitats for butterflies are located outside the riparian zones of the Worm. In the long term, the area may possibly be suitable and reached by the White Admiral and the Purple Emperor. For the White Admiral, the occurrence of wild honeysuckle (host plant) is important, while the Purple Emperor has more overlap with the Stag Beetle habitat (see below). Further away from the water, in the drier forest areas with languishing and dead summer oaks, suitable habitat could potentially form for the Stag Beetle.

Fish

With targeted measures, the quality of habitat for some stream-loving species such as European Minnow and European Smelt can be improved, making their occurrence in the plan area more evident. Both species require undercut banks where roots of alders, for example, overhanging into the watercourse. By removing the current landform and planting alders, this stretch can be improved for the European Minnow and European Smelt. These species are found both downstream and upstream and can easily reach the planning area.

The European Bullhead has been colonizing the Worm from the Rur since early 2001. In 2010, the species already colonized the estuary-Oberbruch section. From the 2018 biomonitoring, it appears that the species is also present upstream of Oberbruch. The fact that the Bullhead has not yet been observed in the Rimburg-Haanrade section, as well as the section upstream of Haanrade, which is very suitable for the species, is probably an indication that the water mill at Rimburg is not passable for the benthic Bullhead. Habitat optimization can also increase the abundance of rarer fish species, which currently reside mainly in the Rur. By removing bottlenecks and landforms and providing gravelly substrate of varying diameters (possibly with the help of local gravel replenishment), habitat for the Bullhead, Grayling and Brown Trout can be improved. For a species such as the Brook Lamprey, it remains difficult to reach the potentially suitable sections near Rimburg and Haanrade from the Rur. For this, sections between the outlet until Rimburg are not sufficiently suitable (too fast-flowing, absence of sludge and detritus banks with gravelly places). The expansion of the habitat for the Brook Lamprey also depends on the reconfiguration of this downstream area.

3.1.2 Ecological opportunities and bottlenecks

This chapter outlines identified bottlenecks by comparing the current situation with the desired state. These bottlenecks describe areas where spatial adjustments are necessary to progress towards the desired state and thus achieve the WFD objectives.

Natural bottom substrate

The Worm is now channelized over most of its length and enshrined in sheet rock, lacking natural dynamics and morphological processes. By giving more space to the stream, it is possible to work towards a more natural image, in which different zones with variation in bottom substrate can be created within the stream course.

Streamside vegetation / buffer zone
The adjacent lands along the current streambed are often used for urban or agricultural purposes. A buffer zone with established vegetation and forest is frequently absent. Establishing riparian vegetation provides shade for the stream, and a broader buffer zone offers opportunities for both wet and dry nature development.

Fish migration
In various locations along the Worm, there are impediment structures in the form of rock debris piles. These bottom traps create a physical barrier, local rapids, and are impassable for many fish species. Constructing meanders can create local variations in flow velocities, which is desirable for many species groups. Additionally, the addition of meanders can (partially) compensate for the slope of the bottom traps to be removed. In areas where there are no possibilities to modify the course, it can be explored whether obstacles can be eliminated through the use of fish passages. For most fish species, removing the impediment structures results in the connection of downstream and upstream habitats. However, for some less mobile species like the Brook Lamprey, they can only benefit from this once the remaining downstream bottlenecks in the Worm (between the Rur and Rimburg) are resolved.

Invasive species
"In areas where new bends and/or banks are created, there is a high likelihood of the dominance of invasive exotic species, particularly in combination with the Large Stinging Nettle. The Himalayan Balsam in particular, is known for colonizing pioneer situations and subsequently becoming dominant. This development hinders the desired vegetation formation. While the removal of invasive exotic species may be partially successful, complete elimination is not realistic. It is therefore important to develop a strategy for approaches to monitor vegetation development after implementation, such as seeding with locally sourced cuttings, prior to the realization phase.

Grasslands
Characteristic of a stream landscape is the presence of flower-rich grasslands, often consisting of mesic meadows with silky bentgrass and foxtail grass. The current situation in the surrounding landscape mainly consists of nutrient-rich grasslands and fields. To establish the mentioned types of flower-rich grasslands, many years of adapted management (mowing and removing cuttings) are necessary. Removing the nutrient-rich top layer would significantly accelerate this process. With only mowing and removal, it is more realistic in the short term to establish herb-rich and fauna-rich grassland interspersed with rough vegetation.

3.2 Morphology
The boundary-defining section of the Worm is largely canalized and confined with rubble. This hinders natural morphological processes, resulting in little variation in flow velocities and substrate in the streambed. At the location of the Kraangracht, an original meander is still present, providing a greater variety in substrate and flow velocity. Downstream from the Kraangracht, the Worm flows through predominantly agricultural and urban areas, where woody riparian vegetation is scarce, and a gradual transition between the streambed and the surrounding land is lacking. The buffer zone (woodland and shrub zone) where natural sediment trapping occurs is entirely absent in this section.

3.2.2 Prospect

The upstream area near Haanrade gives a good idea of the potential natural values of the Worm in the project area. Here the stream is meandering and structurally rich. As a result, a mosaic of habitats is present and substrate variation is high. The morphology largely overlaps with the target image included in report "References and measures for natural water types for the Water Framework Directive 2021-2027" regarding structures in R18 streams (Altenburg, Arts, & Baretta-Bekker, 2018). The zone in which the Worm has historically been free to meander in the project area is up to 100 meters wide. Where the Worm is allowed to meander freely, the riverbed undergoes constant changes. Steep bank erosion occurs in the outer bends, with the loosened material being deposited again on the inner bends and islands. High sediment mobility results in varied patterns of gravel and sand. In areas where there is no room for morphological processes, the introduction of materials such as deadwood can play a significant role in creating a diverse range of microhabitats through variations in flow velocity.

> **STOWA R18 morphology prospect.**
> The stream profile is irregular with wide structural differences; sand with local fine gravel banks, overhanging bank and silted to sandy areas with flowing or still water and local rapids with coarse gravel or boulders. Organic material is present in the form of silt zones, detritus deposits, leaf packs, branches and tree trunks. The stream is partially shaded and located in deciduous forest or semi-open landscape.'

Textbox 1. Description morphology prospect R18. Source: (Altenburg, Arts, & Baretta-Bekker, 2018).

3.2.2 Morphological opportunities and bottlenecks

The Worm is now largely canalized and confined in rubble, resulting in a lack of natural dynamics and morphological processes. By providing more space to the stream system, it is possible to move towards a more natural, varied situation with different stream zones. However, not everywhere is suitable for increased dynamics. In areas with high archaeological value and existing buildings, no adjustments to the course and existing rubble are planned. In other locations where full meanders and natural dynamics are not feasible, small-scale measures may be applied to give the stream a more natural character and somewhat restore morphological processes. For example, removing rubble locally and replacing it with rows of posts, deadwood, and gravel supplementation. These sections can then serve as connecting pieces between ecological stepping stones where there is sufficient space for large-scale reconfiguration with meanders.

3.3 Hydrology

The Wasserverband Eifel-Rur has a hydrological/hydraulic model of the Worm. This indicates that the discharge of the Worm is fairly constant, with an average of 3.5 m^3/s (Ued183; discharge situation exceeded half of the days per year). The elevation from Baalsbruggermolen to the Marienstrasse bridge just over the border with Germany is 17.39 m. The average slope over this stretch is thus 2.54 m/km. The average flow velocities vary from about 0.5 m/s during low summer discharges (Ued330) to approximately 2.5 m/s in discharge situations expected once every hundred years (HQ100) (ProAqua, 2017). There are several obstruction structures/bottom traps in the Worm. These locations experience a jump in elevation with locally high flow velocities. Upstream, these bottom traps cause backwater and lower flow velocities. During high discharges, a part of the adjacent land along the current stream of the river becomes inundated. These lands have no or low protection standards and therefore do not formally pose a water overflow issue that the water board needs to address. Just upstream of the Rimburgermolen, the water board has a measurement point where water levels are monitored. With the dimensions of the current riverbed, a Q-h relationship has been established so that discharge can be derived based on the measured water levels.

3.3.1 Prospect

A meandering course exhibits greater variation in flow velocities and water depths. Particularly in the outer bends, the velocity increases, while it decreases in the inner bends. The additional length of the meanders creates a gradual slope and limits flow velocities. When combined with a narrow summer bed and a wide winter bed, it prevents water level drop during low discharges and maintains discharge capacity during high discharges.

3.3.2 Hydrological opportunities and bottlenecks

Present bottom traps currently cause both excessively high (on-site) and excessively low (upstream) flow velocities. Thereby, turbulent water flows on site create fish migration bottlenecks.
Re-meandering the run can add length to accommodate and more evenly distribute the gradient over current bottom traps. There are also other opportunities to reduce flow velocities at such a gradient. This could include spreading the decay over multiple fish-passable bottom traps or, at one location, bridging a larger jump in the decay through fish passage. Additional resistance can also be created by introducing dead wood into the stream course. By maintaining the current course as a high-water channel, discharge capacity can be secured during high discharges.

Flooding measures

As part of the exploration phase for renaturing, opportunities to create retention in the area were also considered. Based on an analysis of the area, the opportunities for water retention were identified. With this, the peak discharge at high water can be reduced. Therefore, a dam was projected in the Worm valley (red line in figure 3.1).

This is shown for different water levels (or height of the dam) in Figure 3.1. Ultimately, 400,000 m3 of retention is possible. However, this requires land positions on the German side. These measures will be further investigated by the Worm master plan.

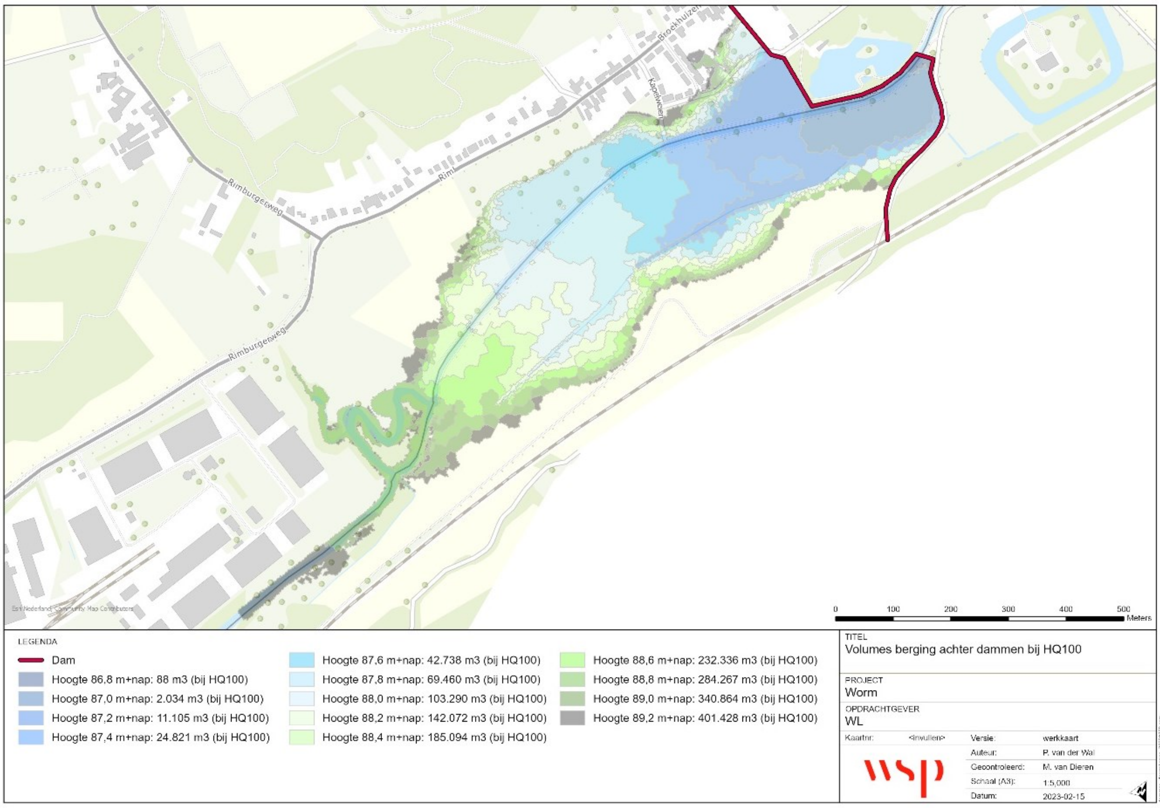

Figure 3.1 Analysis for water retentions Worm in steps of 0.2 meters

3.4 Water quality

The water quality of water bodies throughout the Worm River basin, as the WFD assessments in Chapter 3 indicate, is not adequate. The watershed plan speaks of saprophytes, or elevated levels of organic matter, for more than half of the entire watershed.

The Worm does not meet the target values for phosphorus and nitrogen in the Boundary Watershed as established in the "References and Measurements for Natural Water Types for the Water Framework Directive 2021-2027" (hereinafter "STOWA report") (Altenburg, Arts, & Baretta-Bekker, 2018). For phosphorus the current concentration is between 0.13 - 0.16 mgP/l (Table 4.2), where the target value is <0.06mgP/l. Thus, the concentration of phosphorus is more than double the target value. For nitrogen, the target value is <3 mgN/l, where the current concentration is between 4.2 - 4.7 mgN/l (Table 4.2). The use of fertilizers in the basin leads to the increased nutrient content in the water. Discharges of RWZI effluent also cause nutrient loading. In combination with exposure to solar radiation, this can lead to increased algae growth in slow-flowing waters: eutrophication.

Additionally, the Dutch part of the Worm does not meet the target values for priority substances: zinc, cobalt, and ammonium. The elevated concentrations can be attributed to intensive agricultural use and/or industry throughout the entire watershed of the Worm, particularly upstream in the German section. Contaminations with heavy metals result from past mining activities, waste disposal sites, and discharges of industrial wastewater. Certain heavy metals are also utilized in agriculture, such as zinc in fertilizers.

3.4.1 Prospect

The potential improvement of water quality in the Worm is primarily dependent on influences from the upstream portion of the project area, where the Worm is mainly supplied with effluent. Minimizing discharges and adding additional purification steps to wastewater treatment plants upstream can result in reduced diffuse loading of specific pollutants. Additionally, the extensive use of agriculture and the creation of buffer zones along the Worm can, over time, contribute to an improvement in water quality.

3.4.2 Opportunities and bottlenecks

A healthy water quality forms the foundation of a thriving stream ecosystem. To improve the water quality in the Worm, further reduction of pollution from sources in both Germany and the Netherlands is necessary, including agricultural activities, industry, and effluent discharges from wastewater treatment plants. Wasserverband Eiffel-Rur is implementing measures to optimize post-treatment in wastewater treatment plants along the Worm. Upstream of the project area, three wastewater treatment plants are connected to the Worm: Kläranlage Herzogenrath, Kläranlage Herzogenrath-Steinbusch, and Kläranlage Aachen-Soers. Additionally, the construction of a large retention soil filter at the Aachen-Soers wastewater treatment plant has begun. This will further purify future combined sewer overflows (rain and wastewater) during heavy rainfall before they enter the Worm. Waterschap Limburg is continuously in discussions with the municipality to further improve sewer overflows (reduce size and frequency).

Furthermore, the establishment of a buffering vegetation zone on both sides of the stream holds promise for reducing nutrient-rich runoff from surrounding fields. In the Netherlands, this is being pursued in the context of the Worm reconfiguration project in collaboration with the province of Limburg and the municipality of Landgraaf.

4 Design vision and elaboration

This chapter begins with the design vision and design principles. In an iterative design process, four different variants were developed in which space requirements and the degree of system restoration were distinctive.

4.1 Design vision

Several factors guide the composition of the variants: existing land positions, archaeological (expectation) values, and the location of the historical stream course before canalization (see also WAB019165-D-011-v1 environmental scan). Based on potential land acquisition, three distinctive variants were prepared: a minimum variant (A), a Dutch variant (B) and a maximum variant (C).

Within these variants, several design principles have been applied, which fulfill the design principles and requirements (see also WAB019165-D-010-v1). For example, more space is created within the (transverse) profile for the development of flora and fauna. With shallow banks and more variation in the summer and winter beds, different zones with different water depths will be created. Realizing (micro)meanders adds length and creates variation in (lateral) flow velocities. Bottom traps/fish migration barriers will be eliminated, and streamside vegetation will provide shading on the stream and create a buffer zone with respect to adjacent lands and functions. The accessibility for management and maintenance is ensured with an adjacent maintenance path on both sides (Dutch and German), connecting to the existing road infrastructure. By opening these paths to hikers, the stream becomes more accessible for recreational purposes. In certain sections of the route, no measures are planned due to the preservation of existing values, such as archaeological values near Rimburgermolen/Via Belgica and natural values around the meanders near Kraangracht.

Furthermore, in all variants, a connection of the drainage from Rimburgerweg (a water-conducting road) to the Worm has been incorporated. Improvement of surface runoff from the Rimburg core has not been considered in this phase. Attention to this matter must be given during the development from the preliminary design to the final design, but this is also dependent on further analyses from the Water in Balans project Rimburg and coordination with the municipality.

The adjustments in the cross-section of the stream depend on the available space and follow three principle configurations:

1) Deepen and flatten slopes of the current course on both sides.
In locations where there is limited additional space on both sides of the current course (<20m total), the reconfiguration is limited to creating a more gradual transition between the summer and winter beds by flattening the slopes (Figure 4.1). By reducing the size of the summer bed, water depth increases during low flows, and by widening the winter bed, capacity for high flows can be maintained. The shallow banks provide space for natural bank vegetation and occasional deadwood. Depending on anticipated flow velocities and soil composition, measures may be necessary to stabilize the banks. Especially in outer bends and in the initial phase after construction when there is no strong root development from vegetation, erosion and washout need to be prevented through the use of riprap or (temporary) wooden revetments. While stabilizing banks with riprap may limit the natural development of bank vegetation, localized accumulation of leaves or other organic

material can still create a varied substrate. Deadwood can also be introduced into the stream in various ways, such as stumps, logs, weaves, woody debris, or individual trees. By anchoring the wood, drift can be prevented, and it may contribute to reducing bank erosion.

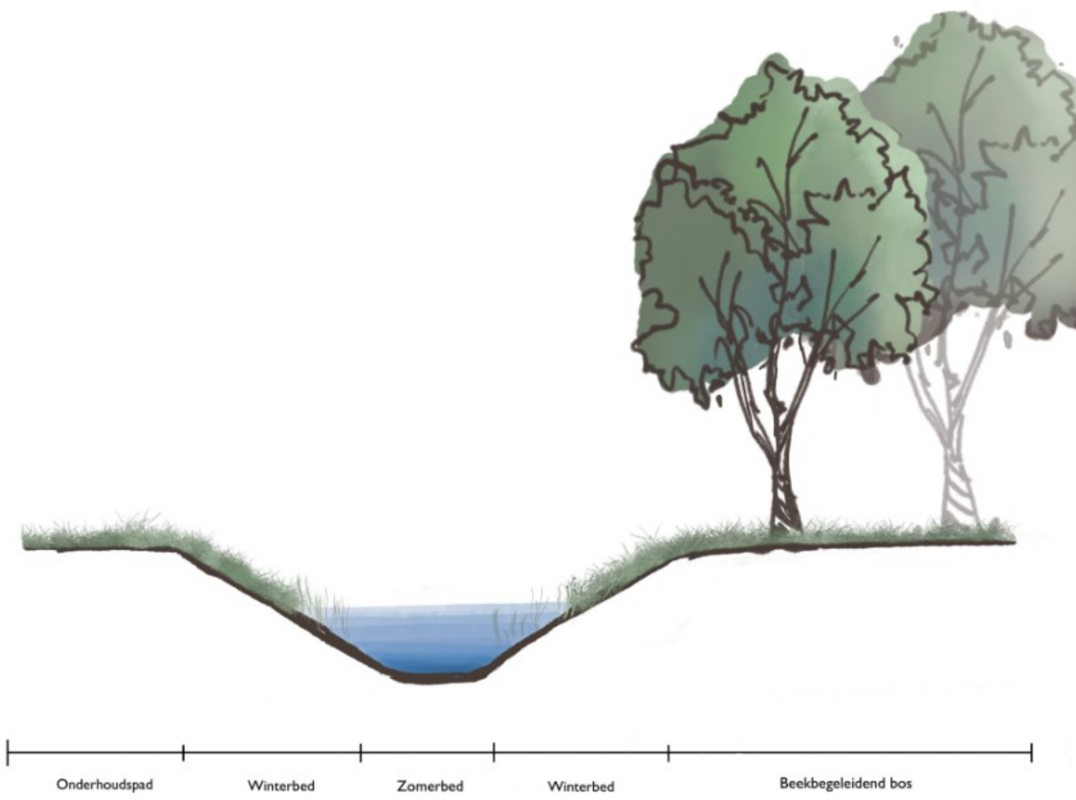

Figure 4.1 Sketch cross section 1, flattening embankments.

2) Flattening slopes and widening to two-stage profile.

In locations where more space is available around the current channel (approximately 20-50 m in total), the cross-section can be adjusted to a (partially) two-stage profile (Figure 4.2). In this configuration, a narrow, shallow summer bed and a wide, higher elevated winter bed with gentle slopes are created. This simultaneously ensures sufficient water depth during low flows and ample capacity for high flows with a limitation of flow velocities. The broad winter bed provides ample space for natural bank vegetation and occasional deadwood. Depending on anticipated flow velocities, soil composition, and space for morphological processes, sand and gravel bars and steep edges may form, or it may be necessary to stabilize the banks using riprap or (temporary) wooden revetments. Especially in outer bends and in the initial phase after constructing new slopes when there is no strong root development from vegetation, erosion and washout need to be prevented if space for natural meandering is lacking. In this situation as well, deadwood can be introduced into the stream in various ways, such as stumps, logs, weaves, woody debris, or individual trees. Anchoring the wood prevents drift and may contribute to reducing bank erosion.

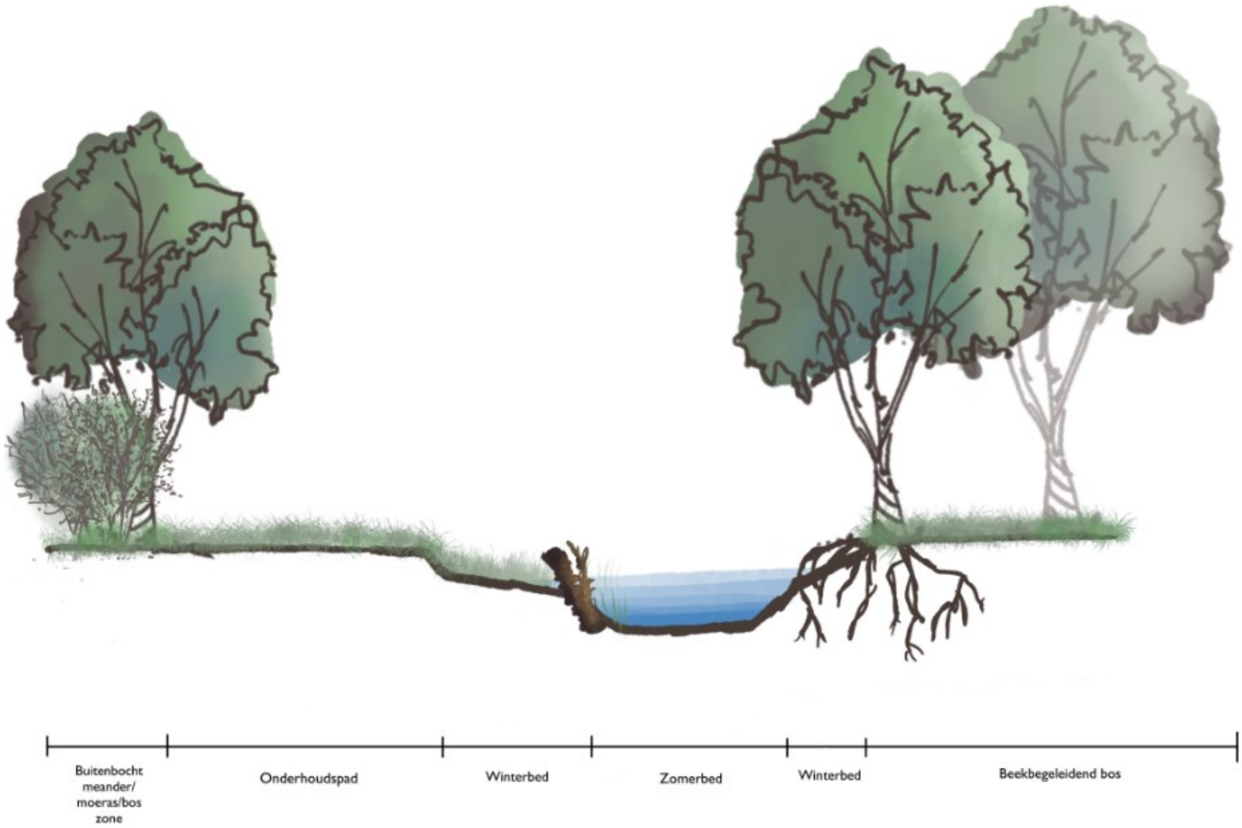

Figure 4.2 Sketch cross section 2, one-way two-phase profile.

3) Restoring meanders and utilizing the existing channel as flood channel

When former meanders can be restored or there is space available for creating new meanders (>>50 m in total), a branch of the current channel is established, with the existing channel designed as a floodplain (Figure 4.3). The space between the new meander and the floodplain allows vegetation development. The floodplain consists of sections of the existing channel, with a threshold on the upstream side (at approximately the water level at T=1 / T=10). The floodplain remains water-conducting even during low flows through a restricted flow passage through the dam on the upstream side.

When creating new meanders, the outer bends, especially in the initial phase after implementation, need to be stabilized. In areas where there is no space for further expansion of the meander, this can be done with riprap obtained from the current alignment. Alternatively, wooden rows of piles and/or deadwood can be used with the expectation that over time, it may decay, and the slope might become sufficiently erosion-resistant through settlement and root penetration. In the further development, this needs to be carefully considered, and monitoring should take place after implementation to determine whether measures need to be taken again to prevent undesirable erosion. Where there is sufficient space, meandering of the Worm may be possible under certain conditions. It is important to monitor these sections and take measures where necessary. Within Waterschap Limburg, there is limited experience with free meandering of streams, and during further development, in good coordination with the Areaal cluster, the conditions for this should be determined.

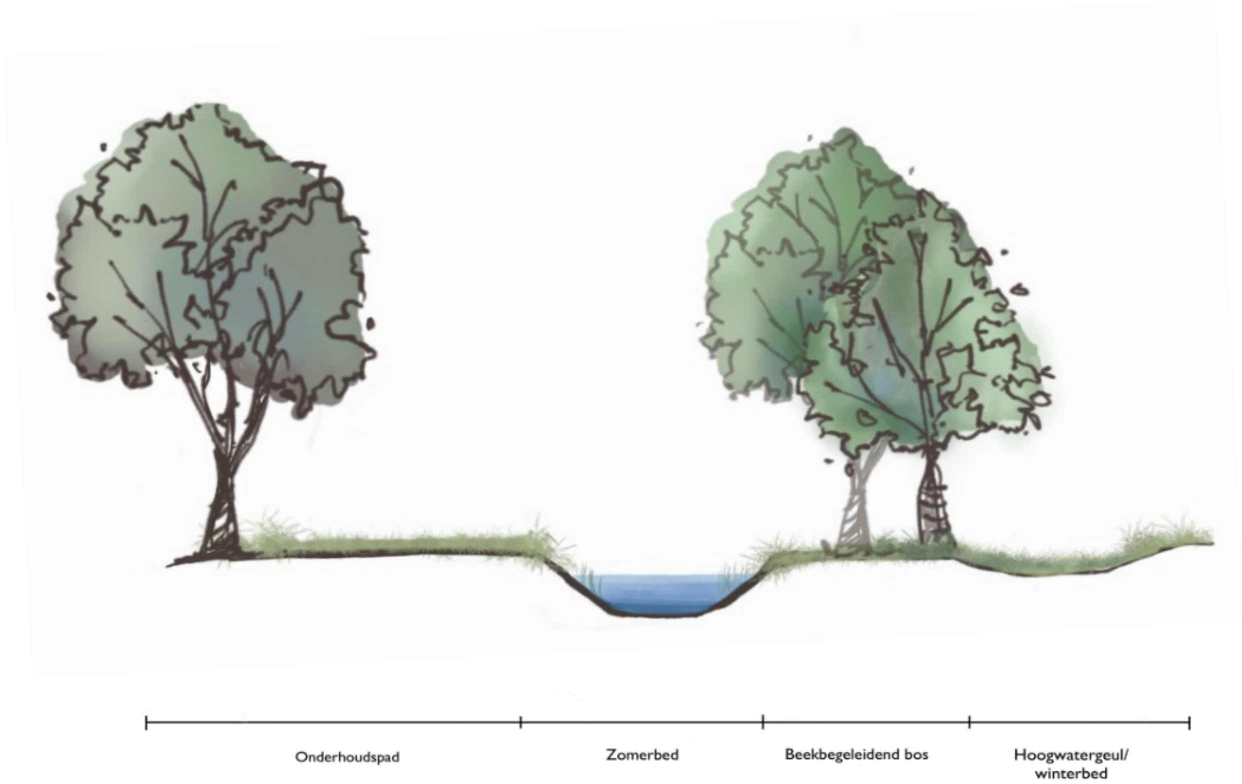

Figure 4.3 Sketch cross section 3, new meander bend with current course as flood channel.

4.2 Minimum Variant A

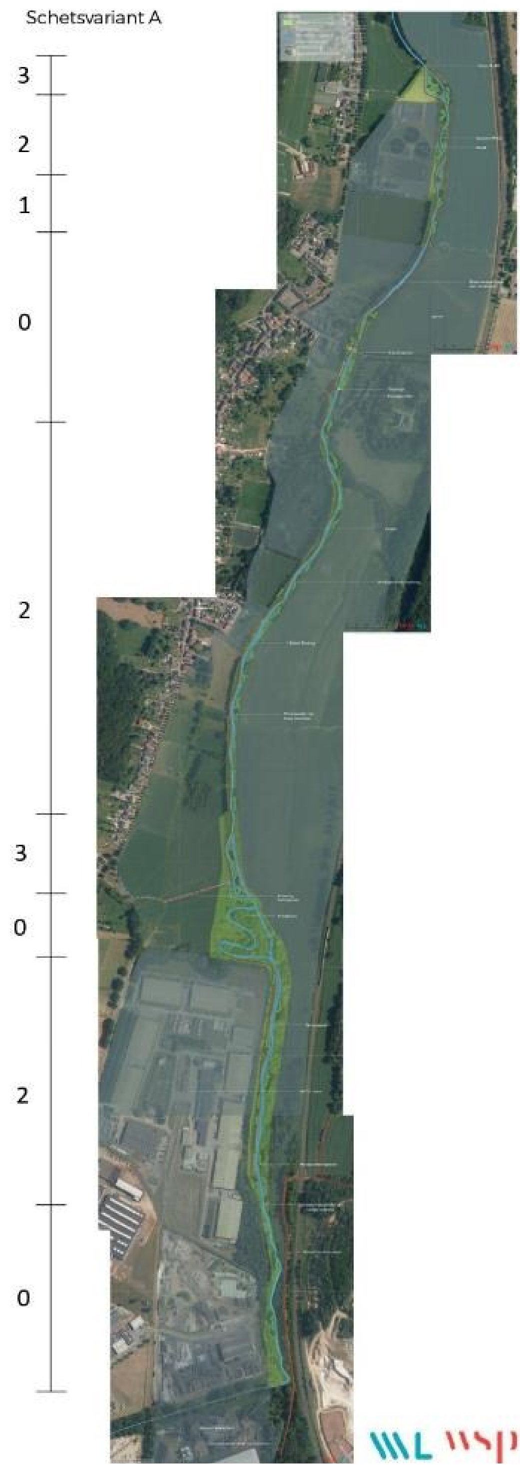

Figure 4.4 Locations of application cross sections Variant A.

0: No measures in profile,

1: Flattening slopes,

2: Two-stage profile,

3: New meander with current course as flood channel.

Variant A (see Appendix 1) includes minimal spatial measures within the lands of Waterschap Limburg, the German Wasserverband and the municipal lands of the current stream course. The measures are mainly focused on improving conditions for other Aquatic flora (WFD task) and has few additional system restoration measures. Where there is space, micro meanders will be constructed to increase the vegetated area on the banks and to create some variation in flow velocity. Within this variant, the sub-parameter woody riparian vegetation in particular can be improved with shading by planting woody riparian vegetation on both sides of the stream. There is less potential for improving aquatic vegetation in this variant.

Description per trace

On the north side of the RWZI, a new meander will be constructed on the plot of Waterschap Limburg, where the current course will be designed as a high-water channel (as per Figure 2.3). On the section along the RWZI, micro-meanders can be realized in combination with a one-sided two-phase profile (Figure 2.2).

Along the plot south of the RWZI, the profile of the current course will be flattened. Further south to the Rimburgermolen, no measures are foreseen due to present archaeological values and the presence of buildings around the Rimburgermolen. Only the bottom trap at the location of the mill will be made fish-passable, to alleviate the major obstacle to fish migration.

From the northern planning boundary to the intersection with Brugstraat, there is a maintenance path on both sides. It is located on the east side adjacent to the property boundary and follows the stream course on the west side up to the national border, where a turning area is provided.

In this variant, the middle section and the section near the NATO site are laid out with a two-phase profile and micro-meanders. Near the NATO site, measures are planned within the current cross-section to minimize interventions on the existing banks so that the risk of erosion is limited and existing natural values can be preserved as much as possible.

To the north of the Kraangracht, more space is available and a new meander (summer bed) has been diverted from the current course to be designed as a side channel. On the east side of the stream, this trace is suitable for new planting of woody riparian vegetation, provided that the management path remains accessible. The west side of the stream is already sufficiently shaded on this route (>60%).

The construction of a ditch along the Rimburgerweg and the walking path towards the Worm will fill in the connection of the drainage of the Rimburgerweg.

Here, there is already sufficient variation in the stream course, as well as streamside vegetation. However, existing bottom traps will be removed/adjusted, and the designated area for planting vegetation and incorporating deadwood into the stream will be formed. This section is distinctive due to its current natural and morphological character. Areas with slow-flowing water are most suitable for the application of deadwood to create habitats for macrofauna groups, including caddisflies and case-making caddisfly species.

4.3 Dutch Variant B

The Dutch Variant B (see Appendix 2) includes measures within the lands of Waterschap Limburg, the German Wasserverband and (adjacent) lands of other Dutch authorities (municipalities and province). In addition to measures to improve conditions for other aquatic flora (WFD task), the available land partly provides the opportunity to restore the historical meanders and achieve a broader system recovery. For the WFD parameter other aquatic flora, this variant offers more opportunities for stimulating water flora, in addition to the development of riparian vegetation for shading. By creating meanders and, in the process, partially removing existing riprap, more space is provided for natural dynamics. In obtaining a more natural substrate, variation in flow velocities, and allowing space for dynamic processes such as erosion and sedimentation, a logical progression is that the coverage of submersed and emergent (above and below water) vegetation can develop more effectively.

Description per trace

In addition to the measures in alternative A, a new meander was also added south of the RWZI. In addition, meanders have been added on the stretch between the historic bakehouse and the existing meanders around the Kraangracht. The pattern of the new meander bends is inspired by the historical course of the Worm, but is only located on Dutch territory on the west side of the existing channel. The intention for the outer bends in the meanders is to stabilize them by using (dead) wood. At critical locations, riprap may be reused. The inner bends will have gradual nature-friendly banks to promote the establishment of aquatic flora. The islands that form on this route between the floodplain and the new channel are particularly suitable for the planting of woody vegetation. A walking bridge over the Worm can create a walking loop starting from Rimburg. The feasibility of such a combined opportunity is also dependent on available funding from third parties.

Figure 4.5 Locations of application cross sections Variant B.

0: No measures in profile,

1: Flattening slopes,

2: Two-phase profile,

3: New meander with current course as flood channel

The design is structured to permit future land availability on the German side, allowing for the implementation of additional measures to restore the historical course (Variant C & C+). By creating a slope/depression in the plots between Rimburgerweg and the Worm, drainage from the road is directed towards the Worm. The layout of the trace at the NATO site is identical to the described layout in Variant C.

4.4 Maximum Variant C

Figure 4.6 Locations of application cross sections Variant C.

0: No measures in profile,

1: Flattening slopes,

2: Two-phase profile,

3: New meander with current course as flood channel.

The maximum Variant C (see Appendix 3) includes measures within the lands of Waterschap Limburg and other Dutch authorities (municipalities and province), the German Wasserverband (WVER) and private parcels on the German side. In addition to the measures aimed at improving conditions for other aquatic flora (WFD task), the available lands provide the opportunity to restore historical meanders and achieve broader ecosystem restoration. Apart from enhancing (WFD) parameters related to other aquatic flora, this variant has significant potential to create habitat for other target species. Particularly, the meander bends offer a diverse habitat for various fish and macrofauna species. Additionally, the lands allow for streamside vegetation and/or nature development in a broader buffer zone with the adjacent lands and functions.

Description per trace

Within Variant C, the historic course (before canalization) forms the basis for the redesign. In this variant, the meanders lie on both sides of the current course. In the middle section, a maintenance path lies on the west side of the meanders and the flood channel (current course). On the east side, in further coordination with the German Wasserverband, the wishes for incorporation of a continuous maintenance path will have to be examined.

4.5 Maximum variant C+ (or sometimes described as D)

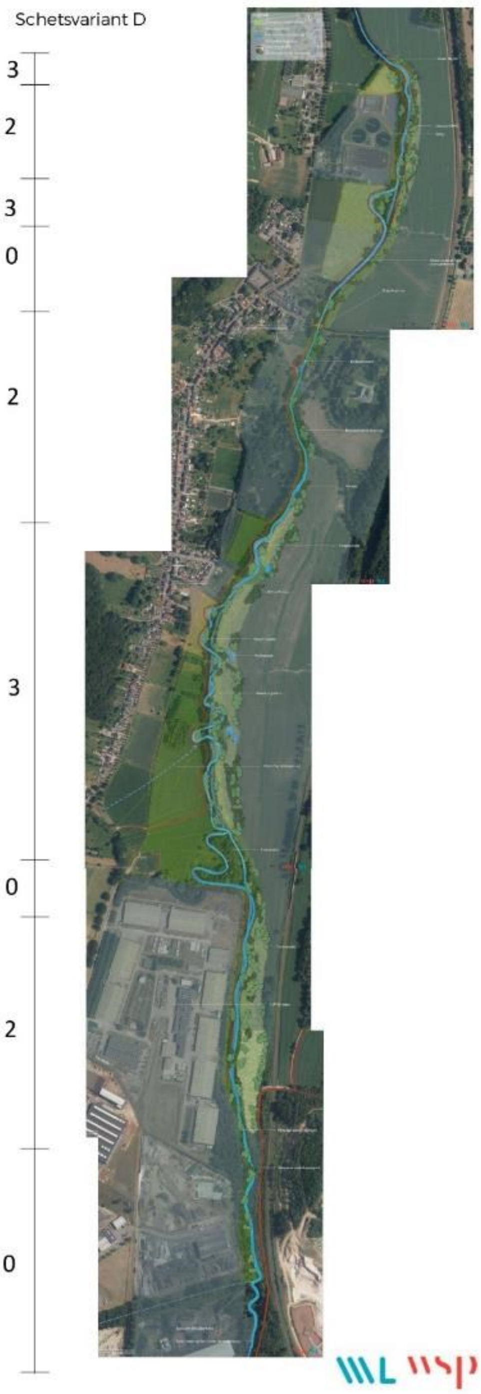

Figure 4.7 Locations of application cross sections Variant C+/D

0: no measures in profile,

1: Flattening slopes,

2: Two-phase profile,

3: New meander with current course as flood channel.

Variant C+/D encompasses an addition to variant C, where, in addition to adjusting the course on the German side, extra space is utilized for adjacent nature development. This strip allows the creation of a woodland zone over a greater length, interspersed with open marshy areas. In the wettest, typically peaty (or clayey-peaty) locations, alder carr woodlands can be established, belonging to Elzenzegge-Elzenbroek. In less wet locations, which are regularly to occasionally flooded with stream water, Bird Cherry-Ash woodland occurs. Where there is sufficient space, a woodland belt can develop with a gradual transition to the buffer zone with flower-rich grasslands (meadows dominated by silky oat grass and tufted hair grass). If this is not feasible, it can develop into herb-rich and fauna-rich grassland with rough vegetation. Adjacent to the open grasslands, there is space to create amphibian pools.

4.6 Evaluation of the different variants

4.6.1 Decision framework

To assess the different variants, a decision framework was developed by the Limburg Water Board. The assessment framework includes seven groups of criteria: 1) hydrological target range, 2) ecological target range, 3) technical, 4) living environment, 5) risk profile, 6) costs and 7) time. For each variant, a weighting was given per criteria group (score 1 poor, 2 moderate, 3 neutral, 4 sufficient or 5 good).

The assessment of the variants is presented in Table 4.1. The rationale for the assessment per evaluation criterion is described in section 5.2.2.

Table 4.1 Assessment of variants A, B and C. Weighting scores 1: poor, 2: moderate, 3: neutral, 4: sufficient, 5: good.

		VARIANT A	VARIANT B	VARIANT C
		Minimum	Dutch	Maximum
	Assessment criteria	**Score**	**Score**	**Score**
1	**Prospect hydrology**			
1.1	System improvement	2	4	5
1.2	NBW standards	3	4	5
1.3	Climate resilience	1	3	5
	subtotal	***6***	***11***	***15***
2	**Prospect ecology**			
2.1	Ecohydrology and biodiversity	3	4	5
2.2	Fish migration	4	4	4
2.3	Chemical water quality	3	3	3
2.4	Ecological water quality	3	4	5
2.5	Climate resilience	1	4	5
	subtotal	***14***	***19***	***22***
3	**Technology**			
3.1	Properties	3	2	1
3.2	Sustainability	1	3	4
3.3	Co-creation opportunities	3	4	5
3.4	Maintainability	3	2	2
	subtotal	***12***	***14***	***13***
4	**Residential and Living Environment**			
4.1	Nature development	2	4	5
4.2	Landscape framing	2	3	4
4.3	Surrounding support	2	4	5
	subtotal	***6***	***11***	***12***
5	**Risk profile**			
5.1	Risk profile	3	2	1
	subtotal	***3***	***2***	***1***
6	**Costs**			
6.1	Investment costs	4	3	1
6.2	Maintenance costs	3	2	1

		VARIANT A	VARIANT B	VARIANT C
	subtotal	***7***	***5***	***2***
7	**Planning**			
7.1	Permit procedures	3	2	1
7.2	Designing and realization	3	2	1
	subtotal	***6***	***4***	***2***
	Overall score	**52**	**63**	**66**

4.6.2 Assesment variants

This section contains the descriptions of the assessment criteria as well as the rationale for the ratings.

1. Hydrology goal achievement

The hydrology target range considers the extent to which the variant contributes to the WFD objective(s).

- 1.1 System improvement
  The extent to which the variant meets the WFD objectives and/or targets, such as headwater elevation, flow velocities, discharge, geomorphological features and thus contributes to achieving good ecological status (GET).

All variants focus on the removal of fish migration barriers in order to restore the system for the fish species. However, true stream system restoration concerning hydrology becomes relevant only when the existing riprap-lined channel is removed to allow hydromorphological processes to take place. The envisioned micro-meanders in different sections of variants B and C contribute minimally to hydrological system restoration. In Variant C, there is more space to create authentic meanders, allowing the removal of riprap in the inner bends and the capture of sediment in the outer bends with anchored deadwood.

- 1.2 NBW-standards
  The extent to which the variant meets the NBW standardization.

With all three variants, the protection level can comply with the prevailing NBW standards. Variant A has a neutral score as this redesign has a minimal effect on the storage capacity. Flattening the banks creates a bit more space for the stream, but on the other hand, the removal of fish migration barriers might increase discharge and flow velocities. Variant B receives a slightly higher storage capacity by creating a new channel while retaining the old one as a floodplain. In Variant C, the storage capacity is optimal. The specific impact on the risk of water overflow is being examined through a hydrological calculation (see Chapter 6).

- *1.3 Climate resilience*
  The extent to which the system can anticipate extremes (dry and wet conditions) from a hydrological perspective is considered. The adaptability to future developments (both drought and increased wetness) is also taken into account, including additional system restoration, space for buffer zones, etc.

In terms of climate resilience, Variant A is not very flexible. The stream system is more vulnerable to change due to possible acceleration of flow velocities by removing fish migration barriers. Variant B includes more room for dynamic processes and is therefore more robust. Variant C scores optimally for climate resilience due to its dynamic character, possible room for expansion and increased amount of storage capacity.

2. Goal Achievement Ecology
In terms of ecological goal achievement, the assessment examines the extent to which the variant contributes to the Water Framework Directive (WFD) objective(s).

- 2.1 Ecohydrology and biodiversity
  The extent to which the variant meets the objective and/or target envisioned by the WFD. Where possible, reference or quantify the achievement of the Good Ecological Status (GES) for other aquatic flora and macrofauna. Ecohydrological effects of changes in water management, such as groundwater extraction, water level adjustments, drying, or wetting, may play a role in this assessment.

Variant A scores neutral for ecohydrology and biodiversity. There will be no deterioration or only minimal improvement. The target values for the parameter 'other aquatic flora' with respect to shading can be achieved by focusing on planting on both sides of the stream (>60% of the stream shaded). However, there will be no significant improvement for the other sub-parameters of 'other aquatic flora' (submerged, emergent, floating). In Variant B, there is more space for meanders and a natural substrate in various sections, resulting in an improving ecohydrology of the stream itself. In Variant B and to a greater extent in Variant C, there is room for the development of different habitats. Bringing back natural dynamics for multiple species groups (macrofauna, fish, invertebrates) is expected to have a positive effect. In Variant C, in addition to improving the ecohydrology of the stream itself, system restoration is also possible by developing different stream zones.

- *2.2 Fish migration*
  The extent to which the design variant enables fish migration so that fish can freely migrate and contributes to achieving the good ecological status (GET). When designing an engineering structure, biological and hydraulic boundary conditions for fish must be taken into account.

In all variants, the bottlenecks are removed. For the Rimburgermolen, further investigation is needed for the integration of a fish passage. This can be achieved either with a more natural fish ladder (as with the Baalsbruggermolen) or through a structural solution. Due to the presence of historical buildings, a modification in the streambed is not considered feasible.

- *2.3 Chemical water quality*
  The extent to which the variant contributes to improving chemical water quality. This could include purification effects of the system.

All variants score neutral with respect to water quality in the current condition. In areas where streamside vegetation is developed, infiltrating water can be filtered. Although Variant C will eventually have a greater purifying effect on chemical water quality, it is not significantly different from Variants A and B, as the influence of the quality of inflowing water is too significant.

- *2.3 Ecological water quality*

The extent to which the variant contributes to improving ecological water quality. These include space for buffer zones and sufficient variation in vegetation and flow.

Variant A scores neutral compared to the current situation, as no significant difference can be made for ecological water quality with the measures described in Variant A. With the increase in variation in flow velocity and substrate in the stream course, ecological water quality may improve. Variant B, and to a greater extent Variant C, contribute to this diversification of habitats for flora and fauna in the stream.

- *2.5 Climate resilience*
  The extent to which the system can anticipate/is resilient enough for extremes (dry and wet) from an ecological perspective. The degree of adaptability to future developments (both drought and water logging) is also considered here, such as stream valley-wide approach, additional nature development, space to retain water, etc.

Variant C scores highest in this category due to the broad approach in the river valley and additional nature development. Variant B is less climate-resistant. The more robustly the river system is designed, the more climate-resistant it is. In variant B, and to a greater extent in variant C, space is created by adding meanders and a buffer zone. Soft banks with woody vegetation contribute to a more resilient system compared to the current situation, including maintaining the water temperature more consistently (low). Variant C is even more resilient due to the vegetation and buffer zones, creating more capacity outside the riverbed to handle excess rainwater in wet periods or retain water during dry periods.

3. Technique

- *3.1 Properties*
- *This aspect concerns the properties of the measures and the land needed to implement them in the variant. If the ownership of the land on which the measures need to be implemented does not belong to the water board and the current owner of the land does not want to implement the measure, this leads to a lower score. We strive for collaboration and sharing responsibilities to achieve a situation in which the measures can be implemented. In relation to ownership, the size or footprint is also taken into account. The footprint that a measure requires is correlated with the effectiveness to solve the bottlenecks. A measure scores better when the footprint is low in correlation to its effectiveness. In locations where there is little competition or sufficient space, the aspect of footprint will have a smaller impact.*

As no additional property needs to be acquired in Variant A, it scores neutral. Variant B scores moderately as although a commitment to use the additional land from Dutch governments has been given, it still needs to be actually acquired. Variant C scores low as this variant requires land from private individuals.

- *3.2 Sustainability*
  Sustainability is scored on the extent to which a variant contributes to realizing the sustainability ambitions as determined in the sustainability sessions and to what extent the variant meets the Ambition Web. The more a variant fulfils/can fulfil these ambitions, the better it scores.

On October 11, 2022, the sustainability session took place with the aim of filling in the Ambition Web (developed by Sustainable GWW Desk) (see WAB019165-D-019-Report Ambition Session - Oct 11,

2022-v2). During this session, it was determined that the highest achievable ambition level 3 was set for two themes: ecology & biodiversity and water, ambition level 3.
The ecology sub-themes are (a) biodiversity and (b) ecological structures. Within the project, the aim is to optimize the entire stream system. This means that the perspective goes beyond just achieving the WFD (Water Framework Directive) goals within the stream channel, contributing to a resilient green-blue connection. There is also a strong emphasis on the sub-theme of structures by reintroducing and allowing geomorphological processes.

For water, the sub-themes are (a) water quality, (b) water quantity and (c) water safety. The ambition level for the water theme has been set at 3. Within the project, the main focus is on preventing pollution from mine rock released by modifications to the stream course. Furthermore, a strong emphasis is placed on water safety. There is no specific water safety task in the area. However, within the project, efforts are being made to explore opportunities for water storage and slowing down peak discharges (Interreg).

For both sub-themes, Variant A can do little to fulfil this ambition. Variants B and C can fulfil these sustainability ambitions to a greater extent, especially for ecology.

- *3.3 Co-creation opportunities*
  This aspect focuses on the extent to which the variant provides external opportunities for achieving goals other than the Water Framework Directive (WFD). A variant can contribute to the objectives of parties other than the water board, and measures can contribute to goals in areas such as recreation, accessibility, education, etc.

Variant C scores high on linking opportunities, as this variant allows broader nature development. Variant B has this to a lesser extent and scores sufficiently. While Variant A scores neutrally because, in addition to coupling opportunities utilized in all variants (recreational path, connection to Rimburgerweg), there is no additional contribution.

- *3.4 Maintainability*
  This aspect relates to how easy the variant is to maintain. The measure performs better in terms of maintainability when the frequency, duration, and effort required for maintenance are low.

Variant A scores neutral in terms of maintainability as there will be limited redevelopment of the area. The more nature development takes place (variants B and C), the more maintenance is initially required. However, the principle of Variant C is that eventually (>20 years), a balance will be achieved, requiring less intensive management.

4. Residential and Living Environment

- *4.1 Nature development*
  The assessment looks at the extent to which the variant contributes to additional nature development compared to the WFD objectives. Measures that, for instance, enhance biodiversity, create ecological corridors or increase the amount of (diverse) green space, offer opportunities for nature development.

Variant A scores moderately on the theme of nature development. Although ecological values improve slightly with the flanking of banks, micro-meandering, and removal of fish migration barriers, there is no space for additional nature development beyond the WFD objectives in this variant. Variant B provides more room for additional nature development, especially in the zones around the meanders. Variant C has the most space for nature development, both in the stream and in the streamside zone.

- *4.2 Landscape framing*
  The landscape quality of an area is closely related to its amenity value. The amenity value describes the experience of the landscape based on visible features, as perceived by the user. Perception is subjective and differs per person, but the effects on the landscape qualities that determine perception can be assessed. This involves the influence on openness, sightlines, characteristic elements, defining structures, perception and image quality of the area.

Variant A scores lowest on landscaping. The redevelopment measures do not add much to the amenity value of the area. Variant B scores neutral by partly restoring meanders according to the historical course. Variant C scores satisfactorily by bringing back natural structures from the stream valley into the area with its characteristic elements such as meander bends and streamside woodland that enhance the experience and image quality of the area.

- *4.3 Surrounding support*
  The level of support indicates the extent to which the implementation of a variant is endorsed. Insights into the level of support for a variant have been obtained based on various meetings. The greater the willingness to collaborate on the variant, the better the variant scores.

For Variant C, there is the most support within the local community, with the assumption that land acquisition can be achieved amicably. Including the German side in Variant C therefore scores better than Variant B, where nature development will mainly take place on the Dutch side, focusing on improving water storage and reducing the risk of waterlogging. Variant A has the least support.

5. Risk profile

- *5.1 Risk profile*
  The risk profile is used to assess a bundle of themes for the variant in question. Aspects such as soil quality, excessive infiltration, archaeology, explosives, cables and pipes are considered for each variant. The fewer the risks, the better the variant scores.

For the implementation of Variant A, the risks are minimized due to its limited spatial interventions. The likelihood of archaeological discoveries in the area is high, and thus, a larger spatial impact could significantly affect the archaeological risks. All variants take into account the presence of coal waste around the NATO depot. A detailed investigation is needed to assess the risk profile related to explosives and soil quality for the various variants.

6. Costs

- *6.1 Investment costs*

This involves a factual assessment of the total investment costs among the different variants. The average investment costs are neutral, with a more expensive variant scoring negatively and a cheaper variant scoring positively.

Construction and investment costs increase as more earthmoving is required and additional developments are planned. Variant C scores the lowest, as this variant involves the most extensive earthmoving and requires the acquisition of a significant amount of land. Additionally, the costs associated with the research and permitting process are expected to be the highest for this variant. Variant B has an average (neutral) score. Due to the minimal spatial interventions required in Variant A, it scores sufficiently well.

- *6.2 Maintenance costs*
  This criteria deals with the cost of maintaining the variant. The measure scores better on maintainability when the frequency, duration and effort required for management and maintenance is low. The starting point for cost estimation is to strive for a sober and efficient management and maintenance. The variants are compared on management and maintenance costs for over a 30-year period. The lower the management and maintenance costs, the better the variant scores.

The larger the area to be redeveloped, the more maintenance will be needed. In the short term, this difference between A, B and C is greater than in the long term. Landscaping the stream as naturally as possible by giving space to natural processes, such as the falling of trees in its course, aims to balance the ecological system and will require less immediate maintenance in the long run.

7. Planning

- *7.1 Permit procedures*
  The extent to which the duration of each variant is influenced by (permitting) procedures.

Permit procedures for Variant C will be more complex and longer than for B and A, as a larger area will be developed. This is mainly due to processing times for research and exemptions for flora and fauna. All variants include work on the German side, so this too needs to be taken into account. This is expected to be almost the same for Variants A and B, but is expected to be more complex for Variant C.

- *7.2 Design and realization*
  This aspect examines the timeframe in which the preparation and implementation of the variant are feasible. The faster the realization is possible, the better the variant scores.

Variant A will be realized more quickly than B and C due to fewer additional factors (permits, land acquisition, support, etc.). Additionally, it is still highly uncertain whether Variant C is ultimately feasible due to the required land acquisition on the German side.

4.6.3 Conclusion

Based on the assessment matrix, it is evident that Variant C achieves the highest overall score. This is mainly driven by the ecological and hydrological goal achievement. Variant B involves fewer spatial interventions than Variant C, resulting in lower goal achievement, but also fewer costs, risks, and land acquisitions. Overall, Variant B scores only a few points lower.

In order to implement Variant C, private lands on the German side are required, for which there is currently no clarity on whether they can be acquired. Discussions on this matter have been initiated, but a careful process is necessary and takes time. To continue with the planning process towards implementation, Variant B has been chosen as the preferred option. In the further elaboration, it will be explicitly taken into account that Variant B may be expanded to Variant C in the near future.

5 Detailling preferred variant

5.1 Detailled elaboration

Developing Variant B into the preferred variant involves dimensioning and detailing the profiles and implementing them along the entire route in accordance with the trace layout described in chapter 4.

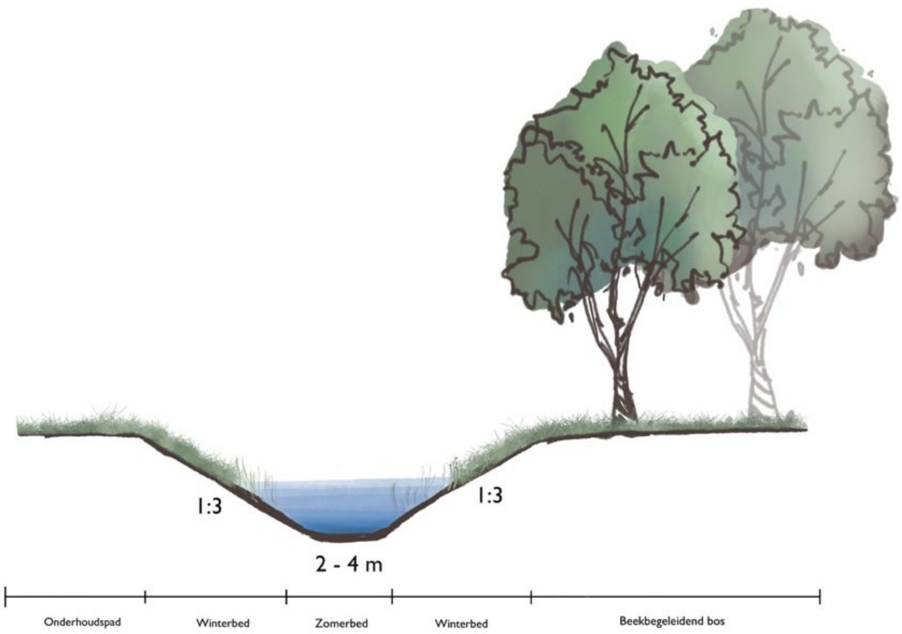

Figure 5.1 Dimensions of profile 1

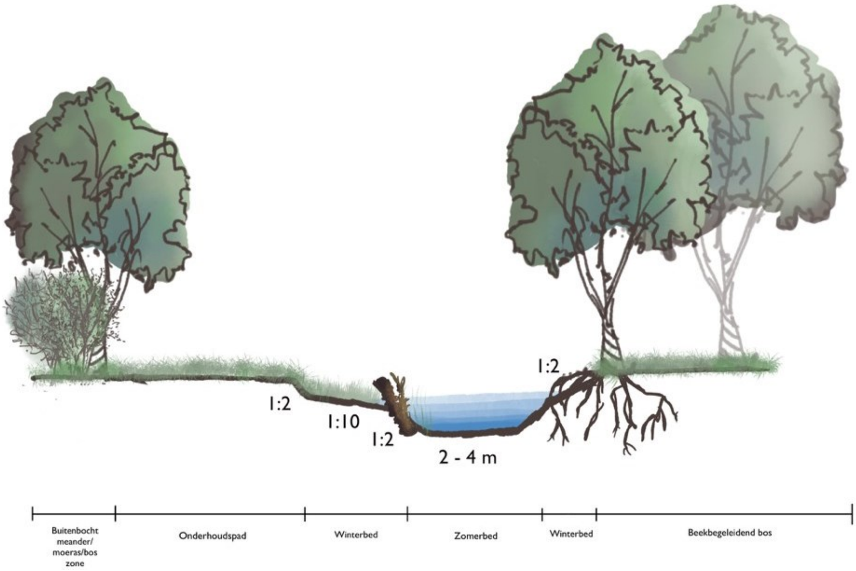

Figure 5.2 Dimensions of profile 2

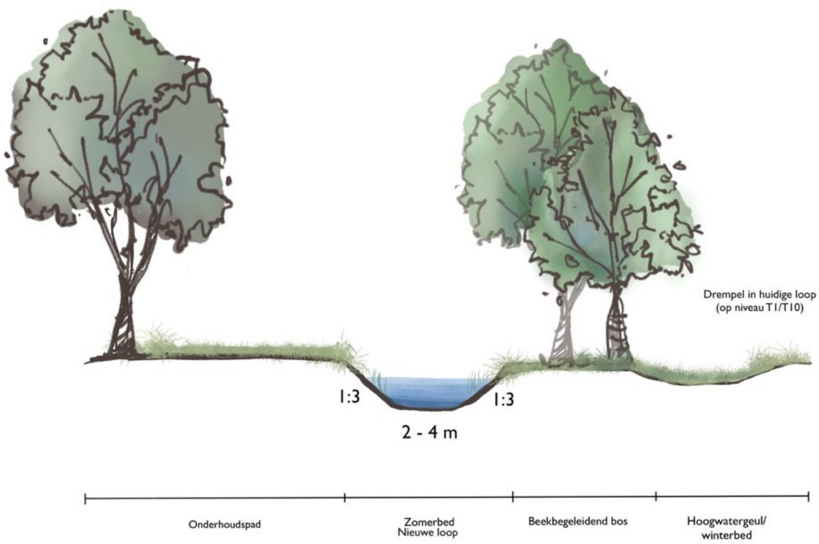

Figure 5.3 Dimensions of profile 3

Figure 5.1, Figure 5.2 and Figure 5.3 show the dimensions with slopes and bottom widths. This was then used to create a full 3D model of the trace in GIS (Figure 5.4).

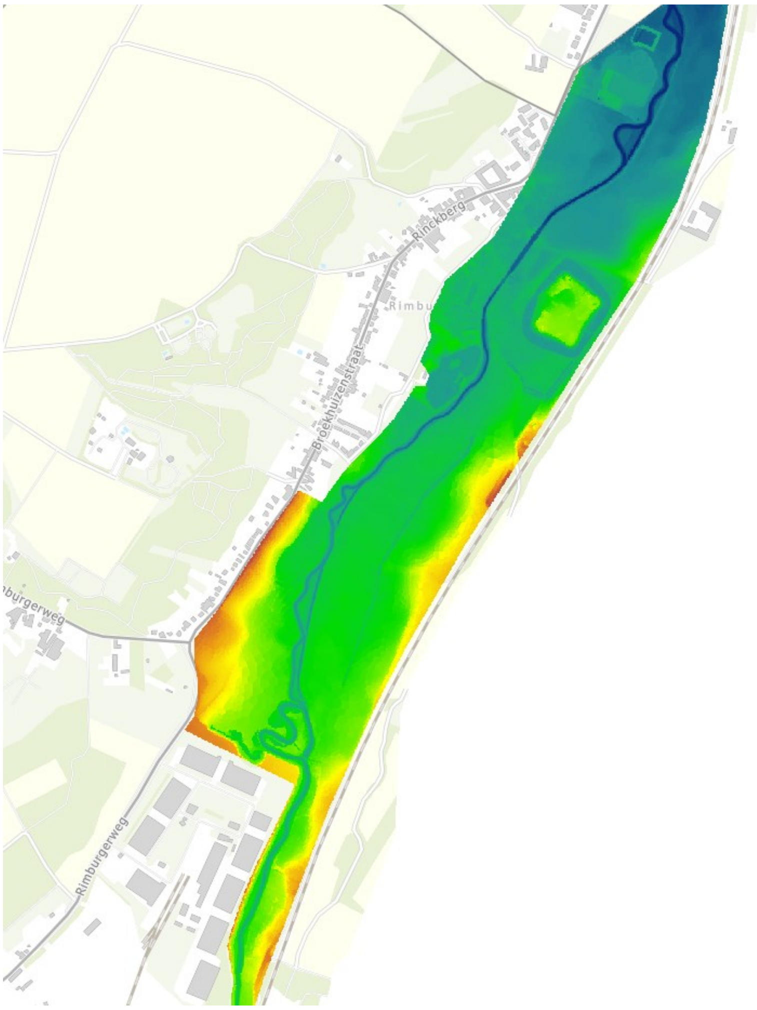

Figure 5.4 3D elaboration in GIS of the preferred variant

5.2 Hydrological modelcalculation

The new stream course of the preferred variant was implemented in the hydrological model of the Worm and calculated for different discharge scenarios.

5.2.1 Water depth

To consider the future water depth, the water depth at the base discharge (Ued330) was considered first. A minimum water depth of 0.4 m is required to form suitable habitat for the various target species (see also section 2.3.2). Appendix 4 shows that this depth is achieved along almost the entire length of the stream. In a few places, however, the depth is less. Between the Rimburgermolen and the Brugstraat, the height difference is such a way that without additional measures, only a water depth of about 0.2 meters is achieved. Also, at the outflow of the existing meander of the Kraangracht, the water depth is less than the desired 0.4 meters (partly due to a slight rise in the bottom level).

However, the effect on the ecological objective there is limited because, with the parallel run, a continuous connection with sufficient depth for species is available. Finally, in the section of the Ansalderbeek inflow and the NATO site, there are a number of places where the minimum depth is not achieved. This concerns locations where the existing bottom traps have not yet been removed from the model schematization. Just downstream of the northern planning boundary, there is also a bottom trap where the minimum depth is not achieved.

Besides the minimum water depth, the high-water scenarios were also considered. Annexes 5 and 6 show the water depths at the normative discharges (HQ20 and HQ100), respectively. Appendix 7 also includes a map showing the difference in water depth between the current situation and the VKV at discharge HQ100.

The most significant differences occur between the NATO terrain and the fishing ponds, where on both sides of the new stream, there is a significant (>0.10 m) reduction in inundation. To the north and south of the RWZI, there is a significant increase in inundation along the new meanders provided there. Furthermore, on the plot between the Worm and the Church of Rimburg, a very local increase of up to 0.4 m can be observed. This involves a local depression that just inundates due to a slight elevation of the surrounding water depth.

Additionally, the inundation depth on the plots around the Rimburgermolen increases very slightly, as well as further downstream from the mill on the German side. This increase is close to the uncertainty margin of the model (approx. 6 cm) and is expected to be resolved with minor optimizations in the design and modeling.

5.2.1 Flow

To assess the ecological functioning of the stream, the flow velocity at summer discharge (Ued200) is presented in Annex 8. During this period, most target species are active, and the desired flow velocity is between 0.3 and 0.8 m/s. The model results indicate that the flow velocities north of the Rimburgermolen are at the upper limit of this range or slightly higher, while south of the mill, they generally fall more within this range. Again, high flow velocities exceeding 2 m/s are observed between the Rimburgermolen and the Brugstraat and at the remaining sediment traps.

Furthermore, the model results show flow velocities that are comparable to those in the meandering section upstream of the planning area. As a result, excessive management and maintenance efforts are not expected in the final situation and can be further prevented by incorporating erosion control measures in the initial situation and around critical areas.

5.3 Design optimization

In the subsequent phase of the project, the design needs to be further detailed and optimized. It is desirable to pay attention to the following components:

- Incorporation of surface runoff Rimburg(erweg)
- Integration of erosion control measures
- Integration of management and maintenance paths (on both the Dutch and German sides)
- Further detailling of making fish passages possible for sediment traps
- Considerations from the model-based analysis

Appendix 1 Variant A

Appendix 2 Variant B

Appendix 3 Variant C

Appendix 4 Variant C+/D