B S C T H E S I S

WATER PURIFICATION AND STORAGE & ECOLOGICAL VALUE;

THE FUTURE OF WATER NORTH OF WOUDENBERG

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COLOPHON

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CONTENT

ABSTRACT

Combining water purification with nature development, is not a new idea, a good system has been developed over the years. This thesis tries to give the best possible option of designing a system that purifies water, but also has room for nature and is future-proof on the plots of a nature organisation near Woudenberg. By researching how natural water purification works and what should be done on the plots of land in question, the background and argumentation of a landscape design is given. That design is visualised is given after the examination of possible models to achieve the requirements.

Key-concepts: Future-proof landscape, natural water purification, ecologically valuable habitats

1. INTRODUCTION

The Netherlands is often praised for the variety of landscapes in the small country. I think one of the most beautiful landscapes available in the Netherlands could be the Gelderse Vallei. The landscape, central in the Netherlands, which was formed by glaciers in the last ice age in the Netherlands where streams of melted glacier flowed of the glacial hills into the valley below.
This process created some very valuable landscapes, aesthetically and ecologically. However, since the last ice age a lot happened in the Netherlands, so in the Gelderse Vallei too.
The natural streams and stream valleys in the Netherlands have been under constant pressure over the last decades. Desiccation, acidification, eutrophication and so on, external factors damaged the streams and valuable stream valley ecology.
After World War II, a lot of streams were canalised by the large-scale land consolidation of those years. Nowadays, by the stream valley repair programme active in the Netherlands, a lot of streams can meander again and wet ecosystems were and are restored (Aggenbach, Bakker, Vegter, & de Vries, 2009). Unfortunately, one problem over the last years, which has not been solved, is eutrophication. The availability of eutrophicating elements like nitrogen and phosphor, is higher than ever before. Therefore, sewage treatment plants and water purification system over the last decade have been targetting this problem. The consequences of eutrophication is the loss of valuable slender ecosystems and plagues of allien plant species.
One particular stream near Woudenberg experienced changes spectacularly but in another way. The Oude Lunterse beek is nowadays one of the streams which is constantly fed by the sewage treatment plant Woudenberg (figure I). The sewage treatment plant discharges in the Liniesloot, flowing north from the plant and discharges in the Oude Lunterse Beek. North of Woudenberg (and Hoevelaar) Stichting De Boom, a nature organisation, acquired plots of land between the Liniesloot and the Oude Lunterse Beek (Figure I) that need a make-over according to the waterboard Vallei&Veluwe.

In this landscape architecture bachelor thesis, I would like to search for a water purificating solution for the plots near Woudenberg. I will start with investigating what natural water purification solutions are available and applicable on these plots of land. However, not only would I like to test the efficacy of the solution, but also the impact on the landscape and, with my knowledge of the bachelor landscape architecture, fit the solutions in the local and regional landscape.

SIGNIFICANCE

This project will have a significant implication in the quality of the discharged water from the sewage treatment plant as well as the ecological value of the landscape. This means that the local ecology in the region will profit from the quality of the water Also the quality of the ecosystem of the Oude Lunterse Beek will profit as biologically improved water will flow through the ecosystem.
By the interventions, the residence time of the water will increase improving the quality of the water and ecological value.
This research and design could show another possible merge between water purification and increasing ecological value

PERSONAL LEARNING GOALS

The foremost goal for this thesis personally is to handle the bigger scales better than previous assignments, as I recognise difficulties with that throughout my bachelor. Secondly, I want to make more touching, photo-realistic visualisations as my visualisation skills are not the best.

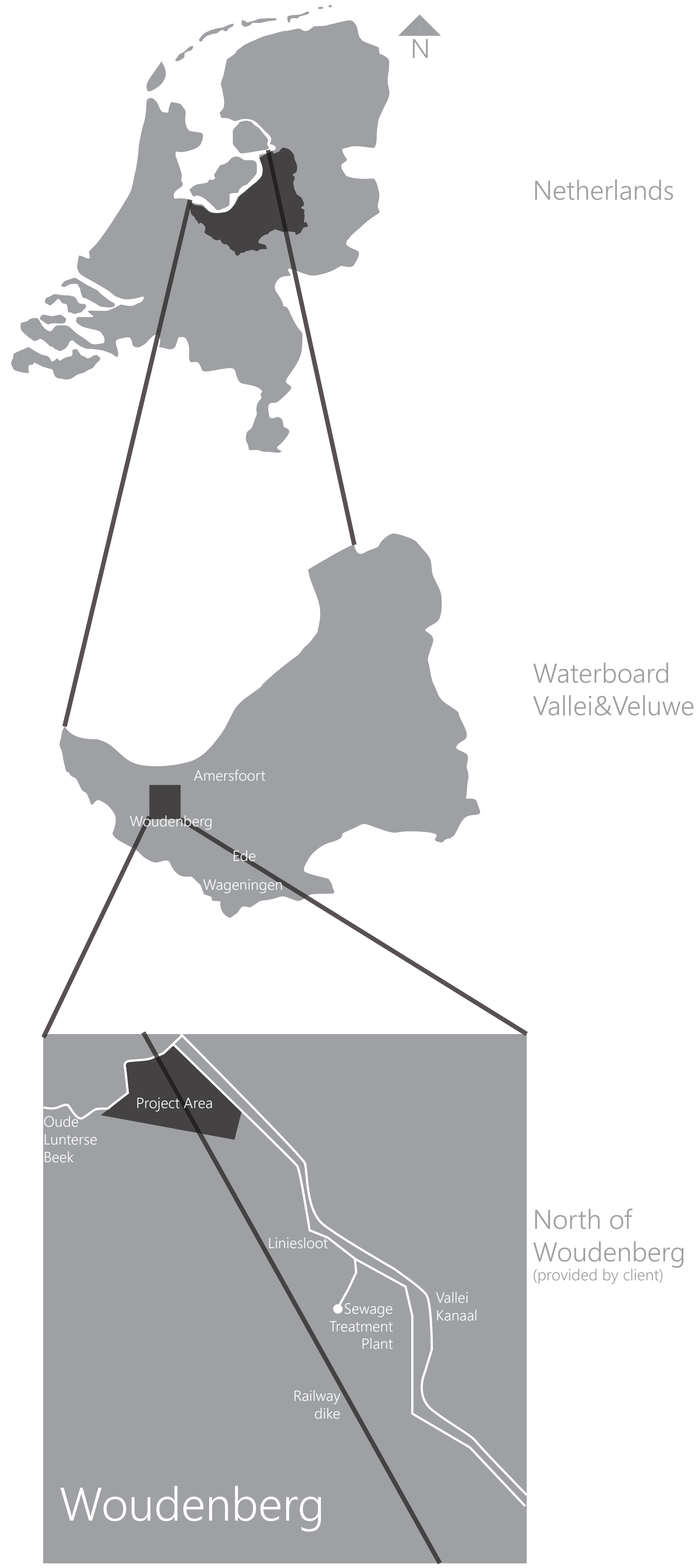

Figure I Location project area

Waterboard Veluwe&Vallei, like all waterboards in Europe, has to make sure that assigned water bodies match the European Water Framework Directive (EWFD) rules. This directive makes sure that the quality of surface water in Europe increases by developing better biological, ecological and chemical waterbodies. To reach these goals, the waterboard Vallei & Veluwe, among others, made this assignment to re-design plots near the discharge point of the sewage treatment plant in such a way that the residence time of the water is increased, the water becomes biologically more active, the ecology becomes more varied. An extra plus would be space for water retention for peek discharges.
Waterboard Vallei&Veluwe, the client of this assignment would ,firstly, like to increase the quality of the effluent in a natural manner on the plots of Stichting De Boom. Effluent is not surface water therefore it is not desirable that effluent is directly discharged in a stream like the Liniesloot or the Oude Lunterse Beek. A waterharmonica is suggested by the waterboard as the missing link between effluent and surface water.

Another demand is to make both streams and the surrounding landscape future-proof. Water storage for periods with heavy rains is also required. Especially because near Woudenberg, a new residential area will rise; Hoevelaar. By 2030, 925 houses will be built (Dutch, 2015). That, not only, has an impact on the landscape but also pressures the capacity of the sewage treatment plant and therefore the discharge in the Liniesloot will be larger.

STAKEHOLDERS

As the waterboard Vallei&Veluwe is the client, their influence is the biggest. Other big stakeholders are the owners of the property (Stichting de Boom), local municipality and the Province of Utrecht. Residents, local farmers and other companies form the group that deal on a day to day basis with the plots and so the design also form a stakeholder.

Stichting De Boom's interest is predominantly in ecological value of the plots, as it is a nature enthusiasts organisation, therefore a natural solution is demanded that fits in the landscape.

OBJECTIVE

To integrate the client's wishes with the point of view from Stiching De Boom, a natural water purification is needed and ecological value should be enhanced. Therefore, the following objective is needed: The objective of this thesis is to design a future-proof landscape which integrates both water purification and ecological value by designing a natural purification process of effluent water which integrates ecologically valuable habitats.

GENERAL DESIGN QUESTION

Leading in this thesis is the designing of the landscape, therefore the general question that is asked, will be answered by a design. In other words:

How can a landscape design combine a natural purification process of effluent water with ecologically valuable habitats?

RESEARCH QUESTIONS

To ensure the design will function as it should be, both technical, ecological, and from a landscape point of view, a couple of questions need to be answered:

What is the quality of the effluent water?
How does a natural purification process of effluent water work?
What are ecologically valuable habitats?

The quality of the water is important to know to ensure the purification process will actually function and purify the water.
Secondly, to design a natural purification process, knowledge is collected how such a process works, what is needed to accomodate such a process near Woudenberg and what it looks like to make sure it fits in the landscape.
Last but not least, knowledge is acquired to make it ecologically attractive and enhance ecological value by creating ecologically valuable habitats.

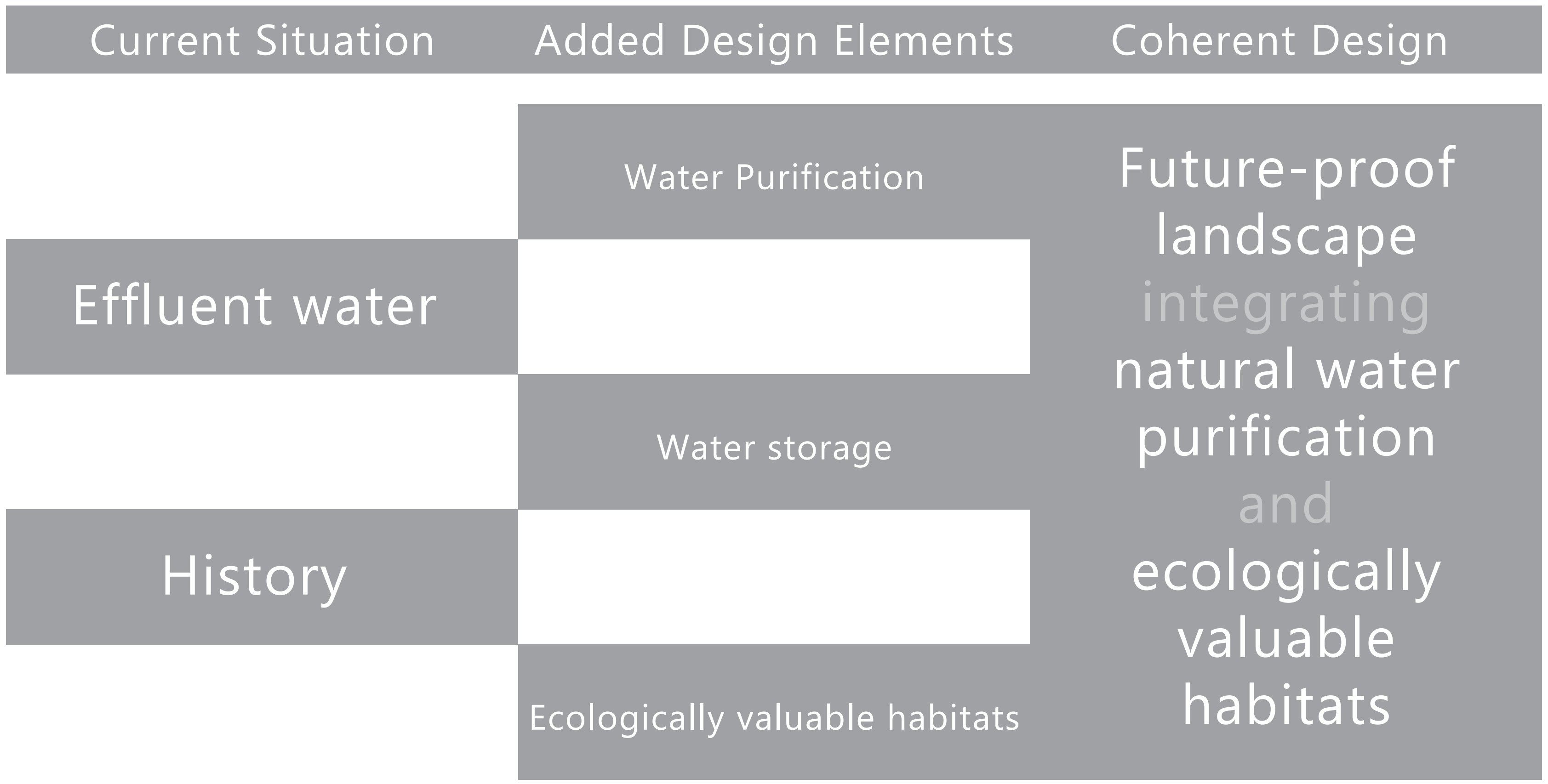

Figure II The current situation and the added concept result in a coherent design objective. The 3 key-concepts in this objective are explained at Key-concepts and the following chapters

DESIGN PROCESS AND MODEL

Linking natural water purification to creating ecologically valuable habitats, a design process is needed that describes a way to deal with these individual design elements.
The Analysis-Synthesis model as described in "The relationship between research and design in landscape architecture", is adjusted to fit this assignment (figure IIIa). This model defines design as a process which applies standard rules or elements, applies those elements and synthesises that in a coherent design (Milburn, Lee-Anne, & Brown, 2003). Important is to note the final step; evaluation. That way a certain control and cycle exists to fit a design to the assignment (figure IIIb).

TIME SCHEDULE

The Analysis-Synthesis model will be followed an is applied to fit in the eight week time frame available for this thesis. The schedule with the application of the Analysis-Synthesis model and the deliverables, is noted in Appendix A.

KEY-CONCEPTS

FUTURE-PROOF LANDSCAPE
The term future-proof is used to emphasize the importance of the fact that this design should last for years and is prepared for the impact of changing climate such as intensified rainfall or longer periods of drought.

NATURAL WATER PURIFICATION
The way I see the most efficient, cost-effective way of water purification is as an ecosystem service (Planbureau voor de Leefomgeving, 2010). Nature can provide such a system (Chapter 2. Natural water purification) (Fleskens, Matte, & van Zanten, 2016).

ECOLOGICALLY VALUABLE HABITATS
The stream-valley where the Oude Lunterse Beek is located, accommodates very ecologically valuable and unique habitat types for flora and fauna (Bijlsma, Janssen, Haveman, de Waal, & Weeda, 2008). The new habitats on the plots should work like stepping stones in the regional network of habitats accomodating species of the region like the Kingfisher and Meadow Brook Jagannathan (Chapter 3. Ecologically valuable habitats).

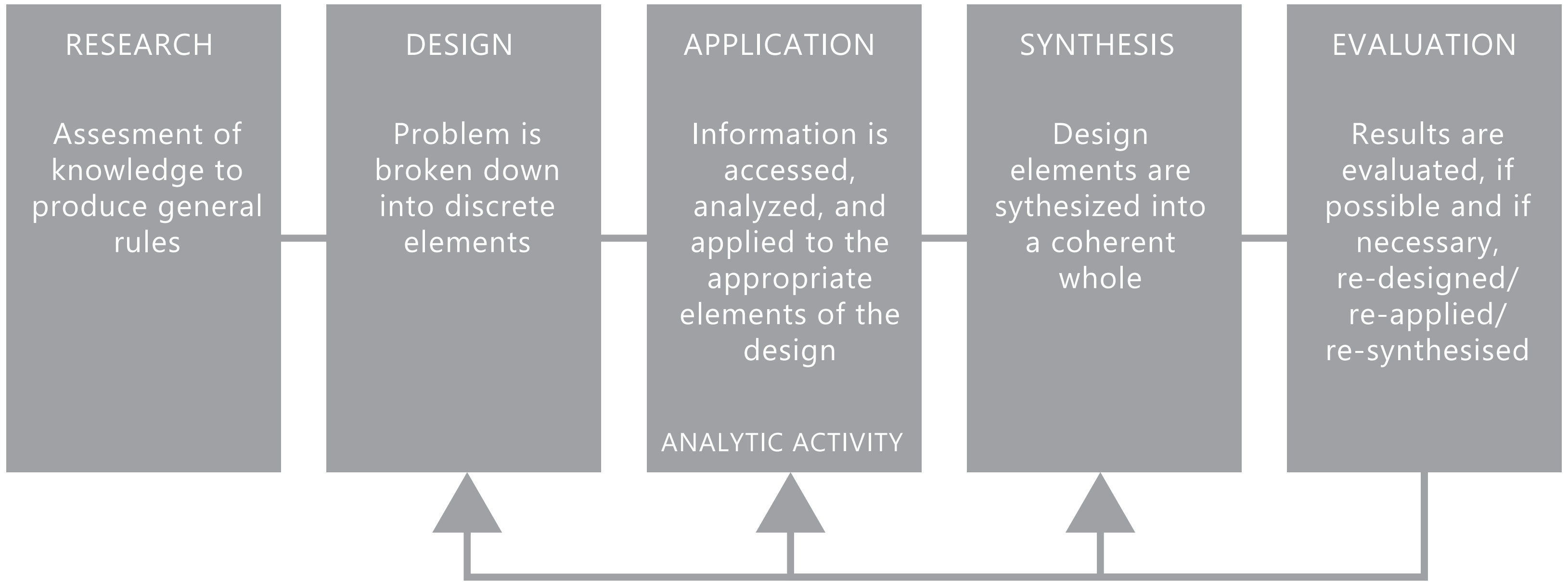

Figure IIIa Relationship between research and design identified by Analysis-Sythesis model (Milburn, Lee-Anne, & Brown, 2003 & author's adjustments)

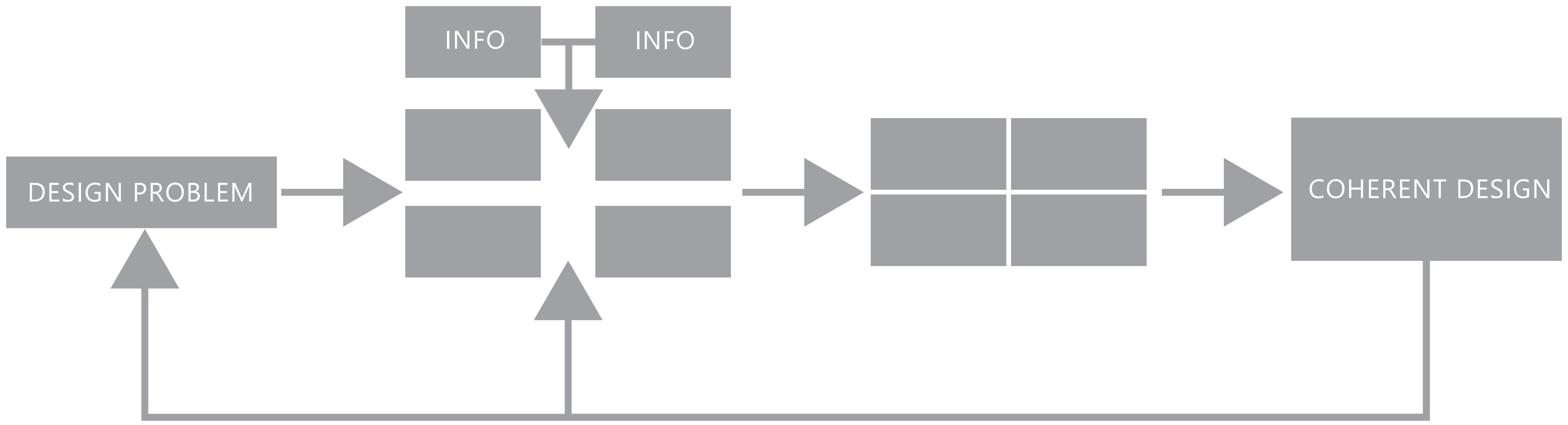

Figure IIIb Schematic diagram of Analysis-Sythesis model (Milburn, Lee-Anne, & Brown, 2003 & author's adjustments)

EFFLUENT WATER; COMPOSITION

The most important thing to know of this water, before applying a purification process, is the number of nutrients as eplained in the introduction (euthropication). Not only does that determine what processes are needed, but measurements before and after purification are important to see if the processes are effective.

A natural creek or stream has almost no nitrogen (total-N) or phosphor (total-P). Those nutrients are not available in this water as nutrients are used by plants and there is a natural cycle in nutrients. With the invention of fertilizers, the cycle has a surplus. Via intensive watering systems around fields of farmers, that surplus ends up in the surface water and, via that, in sewage.
The water in the Liniesloot has on average 4.17 mg/L nitrogen and 0.16 mg/L phosphor (see figure Va). For effluent water, those concentrations are low, which offers perspective in an ecological way. For example, the effluent from Tilburg-Noord has, before the natural purification systems (a weaving stream and a sedimentation pond), a total-N=9.4 mg/L and total-P=1.1 mg/L. The water in Woudenberg has a lower concentration total-N and total-P than the waterharmonica in Soeredonk (appendix A) and the swampforest in Hapert (appendix B).
The second important concentration in the water to know are the undissolved particles. These particles, as the word defines, are not dissolved and float around in the water; a suspension. In the effluent of Woudenberg, on average 2.5 mg/L undissolved particles are present (figure Va). Again, comparing that number with numbers of other sewage treatment plants, this number is low. (appendix A&B) That is mainly the contribution of the sand-filter installed at the sewage treatment plant in Woudenberg.
Figure Vb shows the amount of metals in the water after it leaves the sewage treatment plant. Metals can be toxic if present in large numbers or big concentrations. All the numbers seem relatively low, mostly present due to cars (chrome, nickel) and due to roofs (zinc), gutters (zinc, copper) and pipework which transports the water (lead, copper). These concentrations are not toxic, but the possibility exists that reeds and other plants take metals up and buffer those, leading to a toxic concentration.

Have these number an implication on the landscape design? We know that, compared to other effluent from sewage treatment plants, the number of nutrients is relatively low, meaning that the water purification processes compared to those systems, could be smaller or the mean residence time (MRT) could be lower. This creates the possibility to make a less intensive purification system than reference studies (appendix A&B).

As mentioned in the introduction, effluent is not suitable for surface water. Discharged effluent is cleaned but it is still no ecologically healthy water (Fleskens, Matte, & van Zanten, 2016). To make it ecologically healthy water, a couple of factors need to change regarding the quality of water:

- A diurnal oxygen pattern has to be created (a natural day-night rhythm of the oxygen level)
- The undissolved matter contains too much bacteria
- Biodiversity is low
- Number of nutrients (total-N & total-P) is relatively high

EFFLUENT WATER; QUANTITY

Important to note before explaining and examining the quantity of water is the fact that the system in Woudenberg is sewage from homes, stores and industrial estates, but also the rain water discharge in and around Woudenberg.
The discharge of effluent has two important numbers.
The average discharge over a full year (figure IV). This number does give a good indication in the capacity needed for the purification system and flow rates of the water on average. But we cannot see seasonal differences or peek discharges.
For seasonal differences, there is another number; the dry weather discharge. At Woudenberg the average discharge around 200 days per year is a little less than 300 m^3/hour; 5 m^3/min; ca. 80 liters/sec (figure IV).
We do know the maximal designed capacity of the sewage treatment plant; 1425m^3/hour (Waterschap Vallei&Veluwe, 2017). It is important to keep that number in mind to calculate what happens to the design if that ever would be reached.

	2012	2013	2014	2015	2016	Average
Treated waste water (m^3/d)	9.831	8.807	8.469	9.335	8.652	9.019
Dry weather discharge (m^3/d)	9.723	6.698	6.569	7.084	6.669	6.929

Figure IV Table of the quantity of water discharged at the sewage treatment plant Woudenberg (Waterschap Vallei&Veluwe, 2017)

Nutrients	2012	2013	2014	2015	Average
Total N (mg/L)	3,98	3,94	4,65	4,26	4.17
Total P (mg/L)	0,18	0,19	0,13	0,13	0.16
Undissolved particles (mg/L)	3,10	2,62	3,60	0,66	2.50

Figure Va Table of the concentrations of nutrients discharged at the sewage treatment plant Woudenberg (Waterschap Vallei&Veluwe, 2017)

Metals	2012	2013	2014	2015	Average
Cadmium (kg/year)	0,00	0,08	0,07	0,00	0,04
Chrome (kg/year)	0,00	0,00	2,20	1,78	1,00
Copper (kg/year)	8,60	7.98	5,20	5,58	6,84
Mercury (kg/year)	0,03	0,01	0,00	-	0,01
Nickel (kg/year)	13,37	14,42	9,20	5,31	10,57
Lead (kg/year)	1,38	2.96	5,30	2,75	3,10
Zinc (kg/year)	278,81	228,20	193,20	155,61	213,95
Arsenic (kg/year)	0,00	0,00	1,20	1,57	0,69

Figure Vb Table of the concentrations of metals discharged at the sewage treatment plant Woudenberg (Waterschap Vallei&Veluwe, 2017)

4. NATURAL WATER PURIFICATION

In this chapter, a detailled discription is given about natural water purification, starting with explaining the concept behind it, explaining how it works and concluding what are design implications of natural water purification.

CONCEPT

Natural water purification is not a self-contained concept, but is developed with the concept ecosystem services. Ecosystem services are the benefits of nature to households, communities and economies (Palmer, Filoso, & Fanelli, 2013), such as water purification. Ecological restoration is another concept which it was increasingly intersecting with, and valuable to this case as ecologically valuable habitats have to be integrated in the purification system.

With these ecosystem services in mind, a design concept was quickly found; ecological engineering. Ecological engineering is the design and restoration of natural ecosystems for societal and environmental benefits. It uses engineering principles on natural systems to recover or replace biophysical processes that ideally leads to self-sustaining systems (Palmer, Filoso, & Fanelli, 2013). So to make a natural water purification system, we use the concept of ecosystem services, as it is one, and we can design that with the concept of ecological engineering in mind.

HOW DOES IT WORK?

As shown in chapter "Quality of water", effluent has a complex chemical composition. Important to know for the spatial consequences, is how the different particles are removed from the effluent, explained here.

Organic compounds

Organic compounds are removed either by deposition or by filtration. Those compounds are degraded aerobically (with oxygen) and anaerobically (without oxygen) by microbial growth. A very small part of the organic compounds is removed by uptake of macrophytes (for example: reeds) (Vymazal, et al., 1998).

Suspended solids

In a constructed wetland system, as the hydraulic residence time is higher than in a stream, all settable and floatable solids are removed. The non-settling solids are removed, partially, by bacterial growth. The larger part of solids is settled within the first few meters beyond the inlet as the flowrate drops. The accumulation of solids can be a threat to the performance because the inlet can clog up. (Vymazal, et al., 1998)

Nitrogen (total-N)

Removal mechanisms for nitrogen in the systems include volatilisation, ammonification, nitrification/ denitrification, plant uptake and matrix adsorption. The major part is removed by nitrification/denitrification.

Nitrification is defined as the biological oxidation of ammonium to nitrate with nitrite as an intermediate in the reaction sequence. The nitrifying bacteria, responsible for this process, derive energy form the oxidation of ammonia and/or nitrite is used as the source for synthesis of new cells and bacteria (figure VI A). The bacteria are sensitive organisms and susceptible to a wide range of inhibitors, including high concentration of ammoniacal nitrogen and a narrow PH optimum. As the figure (figure VI A) shows, nitrification is an aerobic process. (Vymazal, et al., 1998)

Denitrification is an anaerobic process by denitrifying bacteria. Denitrification is the reduction of nitrate to molecular nitrogen or nitrogen gases and occurs after oxygen depletion (figure VI B). Most denitrifying bacteria are chemoheterotrophs, obtaining energy through chemical reactions and using organic compounds as electron donor. In flooded soils, for example the banks of a water purification system, nitrification and denitrification happens simultaneously in aerobic and anaerobic parts of the bank and gives a balanced reaction shown in figure VI C (Vymazal, et al., 1998).

Plant uptake

The uptake of nutrients is, logically, limited by the growth rate of the plant. The only thing a plant does is storing the nutrients in the form of biomass. The bulk of the biomass consist of carbon and nitrogen elements, but other nutrients and even metals are stored as well. Important is the process of harvesting the plants, as decomposition returns the nutrients to the water and soil. (Vymazal, et al., 1998)

Phosphorus (total-P)

Phosphorus, present as orthophosphate, dehydrated orthophosphate and organic phosphorus are removed in a wetland system by adsorption, plant absorption, complexation and precipitation. However, most studies have shown that wetland systems are not as effective in removal of phosphorus compared with terrestrial ecosystems. Even though, to effectively remove phosphorus, it is necessary to harvest the biomass, especially free-floating plants as those relatively take up more phosphorus. (Vymazal, et al., 1998)

Metals

Metals are removed by sedimentation, filtration, adsorption, complexation, precipitation, cation exchange, plant uptake and microbial-mediated reactions (oxidation). Important for the removal of metals, is the form the metals are present in as the distribution between particulate and dissolved phases are determined by other processes such as precipitation and diffusion. (Vymazal, et al., 1998)

(A) $24\ NH_4^+ + 48\ O_2 \longrightarrow 24\ NO_3^- + 24\ H_2O + 48\ H^+$

(B) $24\ NO_3^- + 5\ C_5H_{12}O_6 + 24\ H^+ \longrightarrow 12\ N_2 + 30\ CO_2 + 42\ H_20$

(C) $24\ NH_4^+ + 5\ C_5H_{12}O_6 + 48\ O_2 \longrightarrow 12\ N_2 + 30\ CO_2 + 66\ H_20 + 24\ H^+$

Figure VI Biological reactions of nitrification (A), denitrification (B) and a balanced reaction between nitrification and denitrification (C) (Vymazal, et al., 1998).

By stating natural water purification processes, one concept is developed over the last 20 years; the waterharmonica.
The Waterharmonica was first developed by Claassen as part of a contest for innovative water management strategies, set out by the Dutch Foundation for Applied Water Research (STOWA) (Mels, Martijn, Kampf, & Claassen, 2005). The waterharmonica is the link in the chain between effluent water and surface water in creeks and streams. The waterharmonica makes use of an ecologically engineered system that helps to increase the quality of the water.
As mentioned, the system was first developed over 20 years ago, and in that those years, the concept was further developed and applied on a number of sewage treatment plants. This gives the opportunity to use the waterharmonica's as reference projects. Moreover, waterboards throughout the Netherlands are very interested in the waterharmonica as natural water purification, therefore the projects were very well documented and measured.

The waterharmonica is a modular system. There are multiple parts of the water harmonica that independently are used in reference projects (appendix B&C). Every part has its own use therefore designing with the elements is based on the needs of the purification system and searching the right part. We can categorise the modules in 4 groups: ponds, swamp systems with reedfilters, swamp forests and fish traps and ponds.

PONDS

Ponds in the begin of the purification process are mostly used for water retention, as a buffer and to distribute the water evenly over the following parts of the waterharmonica. In these ponds, undissolved particles in the water can sink to the bottom as the flowrate drops. At the first ponds in Soerendonk, water fleas are attracted to eat the undissolved particles and bacteria. Snails would eat the dead fleas, the faeces and algae. These ponds are mostly covered by a dense pack of floating plants, duckweed, limiting the amount of sunlight reaching the water (figure VII).
Ponds can vary in shape, from very constructed, squared with hard corners to more rounded shape ponds with natural banks. The impact on the landscape of a natural looking pond versus a constructed pond is very different but explainable.
In the process of sedimentation, a sludge layer will form on the bottom of the pond. Clearing that layer is easier in a more industrial constructed pond that one with complete vegetation around. Moreover, the type of banks at the pond also determine what kind of flora and fauna will settle in the pond.

SWAMP SYSTEMS WITH REED FILTERS

In these systems, submerged water plants and reeds grow (figure VIII). By growing, the plants use the nutrients available in the water and soil. Those nutrients, mostly the nitrogen and phosphor, are used by the plants to grow. The plants and reeds not only use the nutrients, a diurnal oxygen patern is created as the plants are mostly active by day, also the oxygensystem in the water is composed and the remaining undissolved particles are caught by the reeds. In these systems, aerobic and anaerobic parts exist as reeds move oxygen via the halms. Therefore, these systems can create an active bacteria population with different nitrifying and denitrifying bacteria. The reeds grow optimal when the water level is constant, reeds can lose the purifying use when fully submerged. It is important to keep control over the waterlevel in the system. Another important factor is the harvest of reeds as decomposition returns the nutrients and other elements to the water. Therefore the reeds should be accessible for harvesters.

Figure VIII Reed filters at the waterharmonica in Soerendonk, the Netherlands.

Figure VII Flea pond at the waterharmonica in Soerendonk, the Netherlands.

4. NATURAL WATER PURIFICATION

SWAMP FORESTS

Swamp forests on the other side can submerge a couple times per year and do not suffer from that. Generally, swamp forests do the same things with water as swamp systems with reedfilters. Nutrients are used by the species, smaller plants, reeds, shrubs and trees (figure IX) and a natural oxygen rhythm is created. The difference in a landscape point of view if of course the mass of the plants. Trees have a different impact on the surrounding landscape than reeds. Trees are higher, can be seen from much further than reeds. Trees lose leaves, not if the choice is for evergreens, but still, this has an effect on what happens under the tree in the water or swamp. Trees also bring shade to the water, creating other circumstances than open ponds or other systems. Not only have trees a ecological function, trees also have an aesthetic function and can divide the space making it more readable.

Figure IX Swamp forest in waterharmonica Hapert, The Netherlands

FISH TRAPS AND PONDS

These ponds, biotope ponds, form the connection between the natural purification system and the natural stream system the water is discharged on. In Soerendonk for example, this pond has room for fish to breed, making it a vital part of the stream system (Figure X). This pond too gives a water retention option. If there is a peek in effluent or rain water, the water can be immediately discharged in this pond, buffering the stream and making sure that the swamp systems remain intact. For these ponds, the same decisions have to be made regarding banks and looks (figure XI). However, if the goal is to attract specific fish, circumstances have to be made right for that particular fish. Same goes for birds, insects and so on.

RETENTION TIME

The hydraulic retention time (HRT) has a effect on nitrogen removal (denitrification) (Kampf, Graansma, Claassen, van Dokkum, & Foekema, 2003). Both ammonia and nitrate concentrations went down at a longer HRT in this research. Also the number of different species of plants and animals (biodiversity) in the wetland grew.
On top of that, a diurnal oxygen pattern was noticed. In the ditches with submerged water plants, the daily oxygen pattern resembled with natural, biological surface water. This study showed that the time that the water is in the system (HRT) correlates positively with the removal of nitrogen. Therefore the retention time is crucial in the waterharmonica.

Figure X Fishtrap as the connection between the biotope pond and the stream at Soerendonk, The Netherlands

Figure XI The biotope pond at Soerendonk, The Netherlands. The banks give cover to animals and therefore have a natural look, also providing shadow. On the foreground, Nile Gooses using the pond.

The stream-valley where the Oude Lunterse Beek is located, accommodates very ecologically valuable and unique habitat types for flora and fauna (Bijlsma, Janssen, Haveman, de Waal, & Weeda,2008).
The new habitats can function as stepping stones between larger nature areas as the plots are not large enough to accomodate bigger populations of animals (figure XII).

The local ecology can be divided in two groups, the aquatic nature and the terrestrial nature. The aquatic nature will predominantly be in function of the water purification process. The terrestrial nature is dependent upon the soil, the water and the orientation regarding sun or shadow.

TERRESTRIAL NATURE

To ensure ecologically valuable habitats, the stream- and streamvalley repair programme (beek-, beekdal herstel) could be important. The stream valley repair programme is operational for a number of years to reach the European Water Framework Directive goals on ecological water quality and ecological qualities in the stream valley. The steam valley repair programme is focussed on reweaving old streams that were canalised last century to ensure a fast and big enough discharge of water. Together with eutrophication, ecological quality of streams was lost. The stream valley repair varies from creating natural banks to digging new streams that weave again (STOWA, 2012).

The Liniesloot is a manmade canal, which never weaved, but weaving the Liniesloot could higher the mean residence time, be adaptive to higher peek discharges and increase ecological qualities. Of course there are much differences between natural streams, where the project is for, and this manmade channel. But that does not mean that some elements are usable in this situation specially to reach a higher ecological quality of the water and surrounding land (the 'stream valley').

The programme developed two 'standardised stream cross-sections'.
The first is a two-phase system (figure XIIIa): 2 cross sections are dug, one for the summer discharge and one for the winter discharge which is obviously bigger. This means that there is no inundation outside the winter bed, which increases the flowrate in the winter bed which could mean valuable ecologically valuable habitats, that cannot bare higher flow rates, are lost.

A solution for that could be the wetland system (figure XIIIb): a stream with very easy ascending banks. These banks can inundate, but because these banks have to be over-dimensioned (to ensure water safety), and the flow rate could drop to almost none which could stagnate the flow resulting in dropping oxygen levels and clogging up the constructed system.

Vegetation
The streams that were repaired in this programme were monitored with seed traps and by counting species. The results show an increasing number of species and further analysis showed a clear distribution of species along the hydrological gradient. Species from wet habitats are closer along the stream and species from dryer habitats are higher up the bank (STOWA, 2012). That means there is local succession, nature takes over and create its own circumstances.

The research presented in this chapter showed that the possibilities and knowledge of ecologically valuable habitats is present and this will be applied in the chapters showing the design.

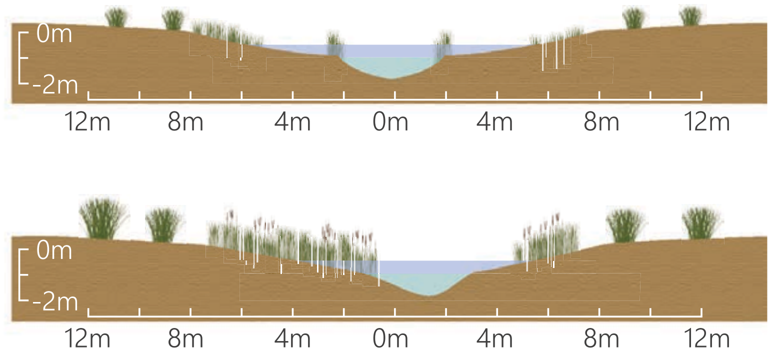

Figure XIIIa The two-phase system, on top the designed profile, on the bottom the profile after some time subjected to erosion and sedimentation. The left bank, inner corner, is sedimented and the right bank, the outer corner is eroded. Originally drawn scale 1:100

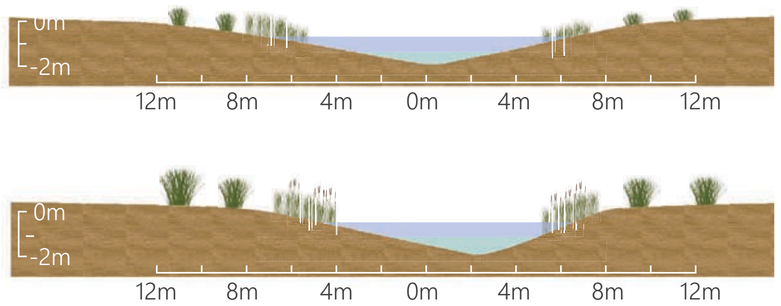

Figure XIIIb The wetland system, on top the designed profile, on the bottom the profile after some time subjected to erosion and sedimentation. The left bank, inner corner, is sedimented and the right bank, the outer corner is eroded. Originally drawn scale 1:100

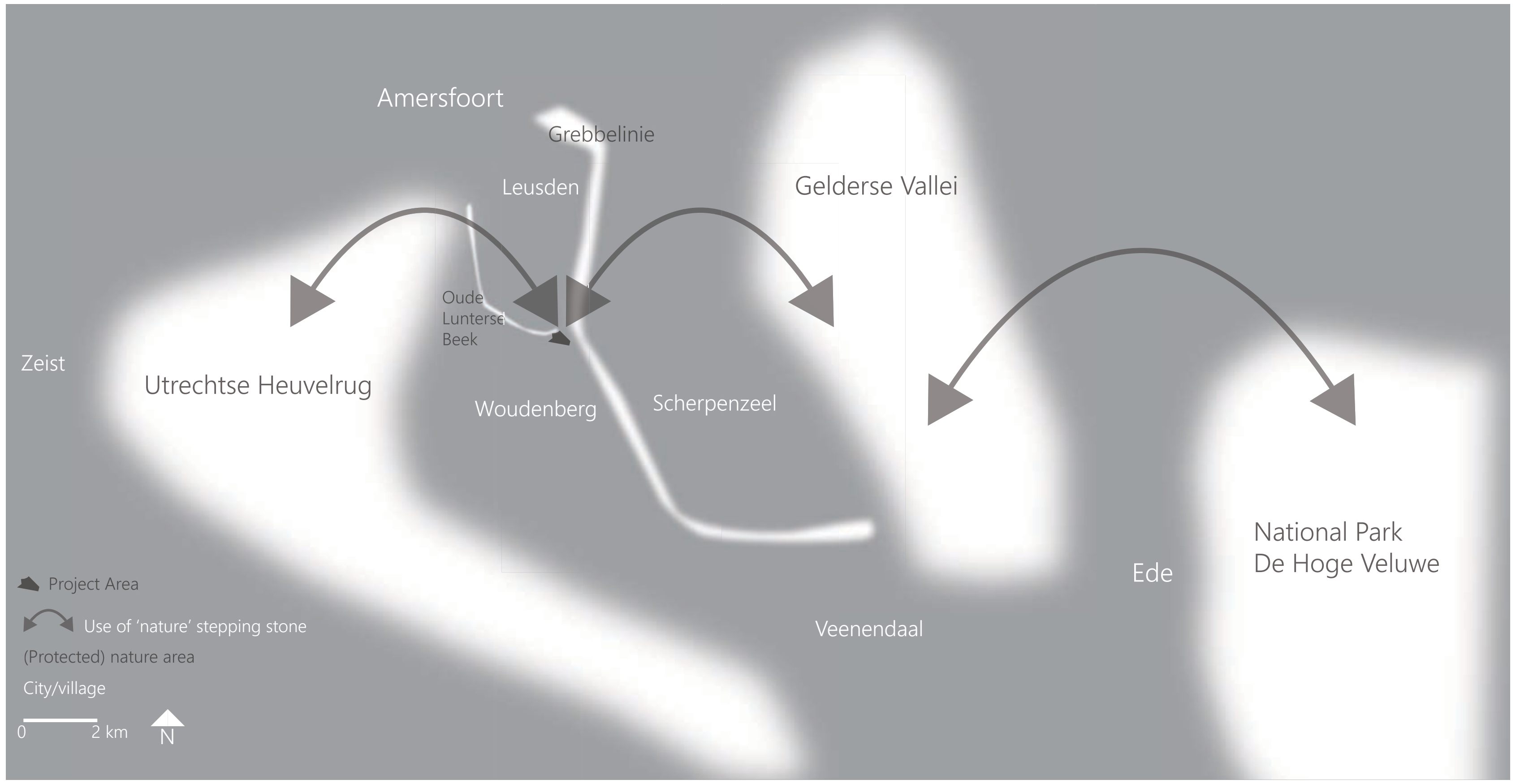

Figure XII Map of the region around the plot near Woudenberg, explaining the possible ecological function of the plots in the regional network.

MAINTENANCE

When touching upon habitat creation and which circumstances and possibilities this area has, it is valuable to know how these system have to be maintained.
The most important maintenance for this system, is once or twice a year a full harvest of the flowfields. The reeds have to be harvested and removed to make sure the nutrients, metals and other particles from the water, taken up by the aquatic flora, are completely removed from the area (Fleskens, Matte, & van Zanten, 2016). Depending on the concentration metals but also medicine residues, the reeds can be used as biomass or should be destroyed with other methods because of those residues.
The first years, the maintenance can be more intensive because the reeds have to inhabit the flowfield, but the water is very fertile therefore other, pioneering species can grow in massive numbers. These, mostly free-floating plants, can prevent the reeds to grow and those plants have to be removed to give the reeds a chance to grow (Fleskens, Matte, & van Zanten, 2016).

STICKLEBACK SYSTEM

On Texel, the waterboard faced almost the same circumstances as in Woudenberg. In Texel, a constructed wetland is created to change the effluent into biologically active water and to enhance the natural values on the island of Texel. Just as this thesis, the idea was to combine natural water purification with nature development. The biggest difference is that Texel is an island and Woudenberg is in the middle of the Netherlands. At Texel, the waterboard developed a step-wise food-chained water system called the kwekelbaarsjes system (stickleback system) (figure XIII).
Daphnia, a water flea specie, was at the basis of the food-chain. The effluent was lead through a constructed wetland where daphnia amongst plants and reeds, made the water biologically suitable, in that case predominantly for fish. The explanation why this system would work is the availability of enough nutrients in the effluent, as is the case in Woudenberg.
As the Daphnia concentration is big enough, the Daphnia can be harvested and transported to a deeper part of the wetland to be used as food for fish such as the Stickleback. In the case of the Texel development, a shallow part follows, to enhance Spoonbills to forage on the Stickleback and other fishes. The Spoonbill is a highly valued specie of bird on Texel by inhabitants as well as tourists which play a big role in the local economy (Kampf, Graansma, Claassen, van Dokkum, & Foekema, 2003).

Of course this system cannot be copied and work in Woudenberg but it shows that with the right focus, ecologically valuable habitats and in this case food-chains can develop, even on a small island like Texel based on effluent from a sewage treatment plant.

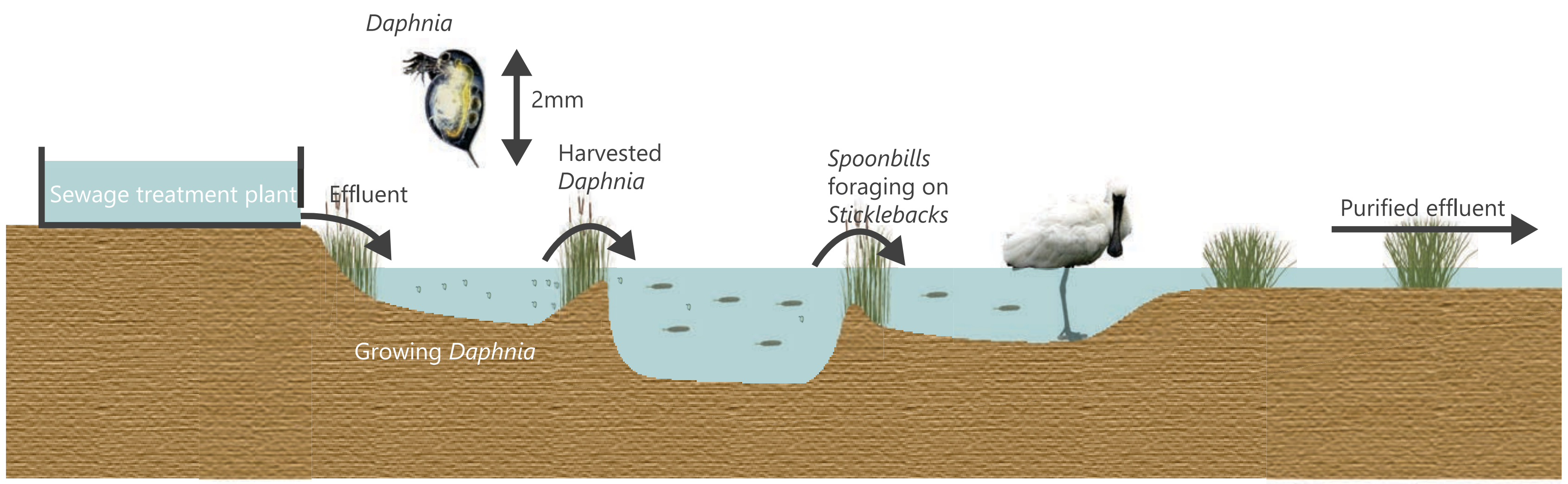

Figure XIV A schematic drawing of the stickleback system (Kampf, Graansma, Claassen, van Dokkum, & Foekema, 2003)

The plots, as mentioned, are property of Stichting De Boom, a regional nature organisation. The story of the plots, told by the waterboard during an excursion around the area, is that the plots were all farmland and acquired by De Boom when the farmer retired. That was about 5 years ago. De Boom planted the area with larger shrubs and leave it to create habitats. The problem is, that the soil is full of nutrients left by the farmer and very wet, therefore a couple of larger, stronger plants like rushes (*pitrus*) and grasses can survive. The water would only be around 40 cm under the surface according to the waterboard. The current situation is not what the nature organisation had in mind, but they leave it like it is now. The waterboard would like to make a natural purification system on the plots as the use of the plots now is minimal, as mentioned.
In this analysis the borders of the plots will be explained and opportunities and problems will be appointed.

In the east, the plots are bordered by the Grebbelinie (figure XIX p. 15). The Grebbelinie is a 16 - 18th century military defence line, over 60 kilometres long. It is a water line; a defence system of forts, dikes and inundation fields. In case of danger, the east side of the Grebbelinie, Gelderse Vallei, would be set under water, making it very hard for approaching enemies to reach the west of the Netherlands (Fähnrich, Frank; Adviseurs, BügelHajema, 2011). Even though the defence line is not used anymore, it still is an iconic element in the landscape. From north to south, it is a long line, a dike, mostly 6 meter higher than the rest of the landscape (figure XV & XVII). Along the line, there is always flowing water, near Woudenberg that water is the Valleikanaal. The Grebbelinie accommodates a few forts, most works are made from dirt therefore sometimes invisible in the line. From east to west, the line always has a large, open area in the east to make it available to inundate and to have a good view over approaching danger. The west side of the line, where the plots are located, the ability to move troops was the only necessity. On the dike itself, high trees characterise the line, making it visually even higher. A plus was that fuel for fires, wood, was always around. (Fähnrich, Frank; Adviseurs, BügelHajema, 2011). Because the plots are flanked by the Grebbelinie, they are in the respectzone around the Grebbelinie. The rules of the respectzone apply to buildings and courts of the farms, but is applicable also to interventions in the landscape. For example, the orientation of facades of the farms to the line is important, therefore the orientation of lines in the landscape will be important too, especially higher elements.
The plots are crossed by a disused railway dike (figure XVI). The railway used to be the connection between Amersfoort-Kesteren and Keulen, Germany (Oudheidskamer Woudenberg, sd). The straight line element in the landscape is flanked on both sides by trees and, near Woudenberg, 3 meter higher than the surrounding landscape (figure XVI & XVII). The railway dike is important because of the cultural heritage, the story it tells and the congruous whole because most of the stations and bridges are still intact along the line. Nevertheless, a culvert was dug under the dike to water off a drainage ditch along the old farm plots. Also the dike is crossed but set through via a bridge over the Oude Lunterse Beek.

Figure XV The Valleikanaal east of the Liniedijk. On the left, the Liniedijk is shown, characterised by high trees.

Figure XVI The plots in question, bordered in the background by the disused railway dike.

Figure XVII Relief map of the plots. This shows the difference in heigt between the dikes and the rest of the plots. What is also shown is that the slope of the dikes is very steep as the height is immediately meters higher than the rest of the landscape.

In the north, the plots are bordered by the Oude Lunterse beek (figure IXX). In 1935 and 1949 the Valleikanaal was widened and deepened. Among others, the Lunterse beek was interrupted to create the Valleikanaal. From that moment, the whole Gelderse Vallei hydrologically is discharged upon the Valleikanaal. The Valleikanaal was dug straight through the Lunterse Beek, therefore the upper part discharged on the Valleikanaal, and the lower part has no natural water supply. Because the Lunterse beek was cut through, the part from the Valleikanaal to "de Woudenbergse Grift" is called the "Oude Lunterse beek" and the part from "de Woudenbergse Grift" to Amersfoort is called the "Heiligerbergerbeek". (Klink, 2010)

When it is dry, the Valleikanaal also supplies the Oude Lunterse Beek but that means that the water eutrophicates and a lot of leaves land in the stream. (Klink, 2010) The leaves make the water stand still, leading to oxygen problems at the bottom of the stream and a duckweed deck on top of the water, blocking out sunlight.

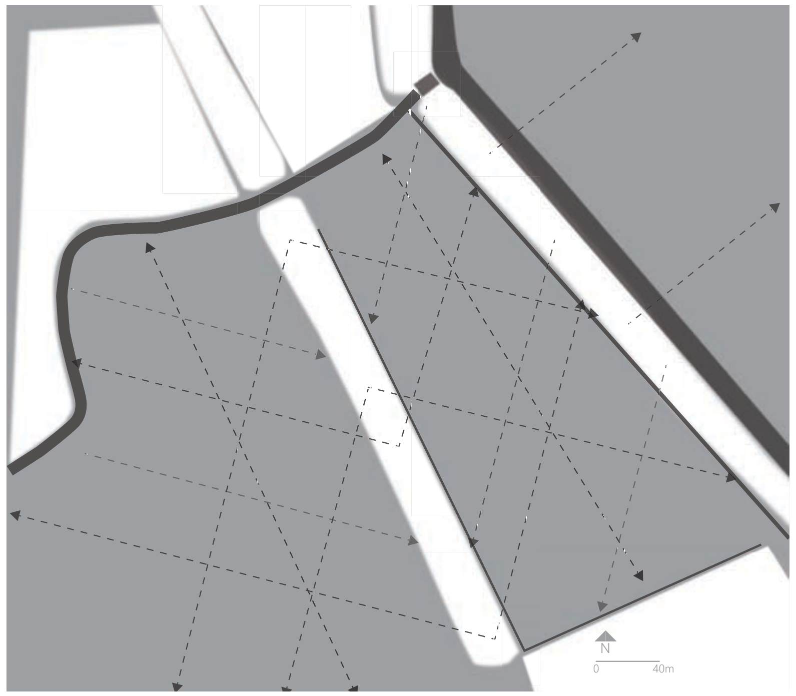

Figure XVIII Visual relationship within the plots and to the surrounding area.

The visual relationship within and from the outside of the plots is displayed in figure XVIII. Because the borders are all formed by trees and tree lines, the plots are visually isolated and the openness within the plots gives enough visual space to enhance the plots. The availability to have a clear overview is special here as two higher elements are located in and along the plots in the form of the Liniedijk and the disused railway dike. Both elements give the opportunity for recreational routes as those are already present.

The Liniedijk has a Klompenpad (paths of an agricultural hiking network) running over it and also over the railway dike there is possibility to hike over a trail. The Valleikanaal and Oude Lunterse Beek are part of a local canoeing network, giving a different experience of the landscape than hiking upon the dikes (figure XIX).

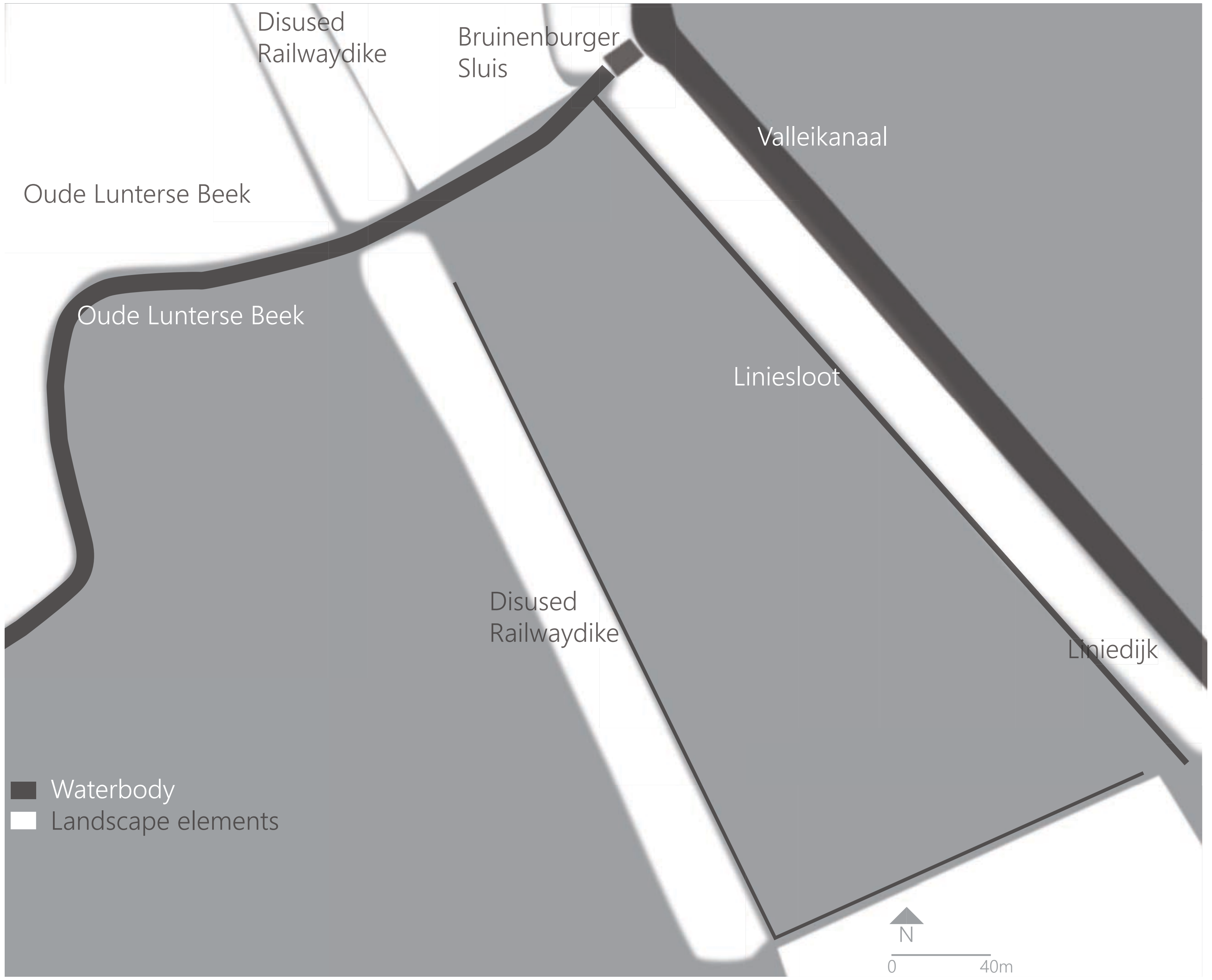

Figure XIX Inventarisation of the plots and surrounding landscape elements near Woudenberg.

The purpose of the following models is to search for the best possible system to purify water and to make it ecologically attractive and to search for the best suitable landscape solution.

MODEL I - MEANDERS

The first model (Figure XX a) is to create an artificial meander with the look and feel of a natural meandering stream. This scenario would increase the residence time of the water substantially as the stream gets longer by all the turns. This system would give the opportunity to make one, long reed filter to purify the water. In the turns, the water's flow rate fluctuates between the inner and the outside corner, giving opportunity for sedimentation and erosion, making the situation as natural as possible. When the Liniesloot flows in the Oude Lunterse Beek, the stream in the current situation gets wider, therefore the artificial meander of the Oude Lunterse Beek, should be able to accommodate more water than the Liniesloot as that is the situation in the current situation.
The total mean residence time of this model is calculated (based on volume and flowrate) at 0.06 days.
Advantages of a meander is the value of the inner and outside corner regarding ecologically valuable habitats and the purifying power of the reeds between the corners.
The disadvantage is that the residence time still is very little comparing to reference studies (appendix B&C).

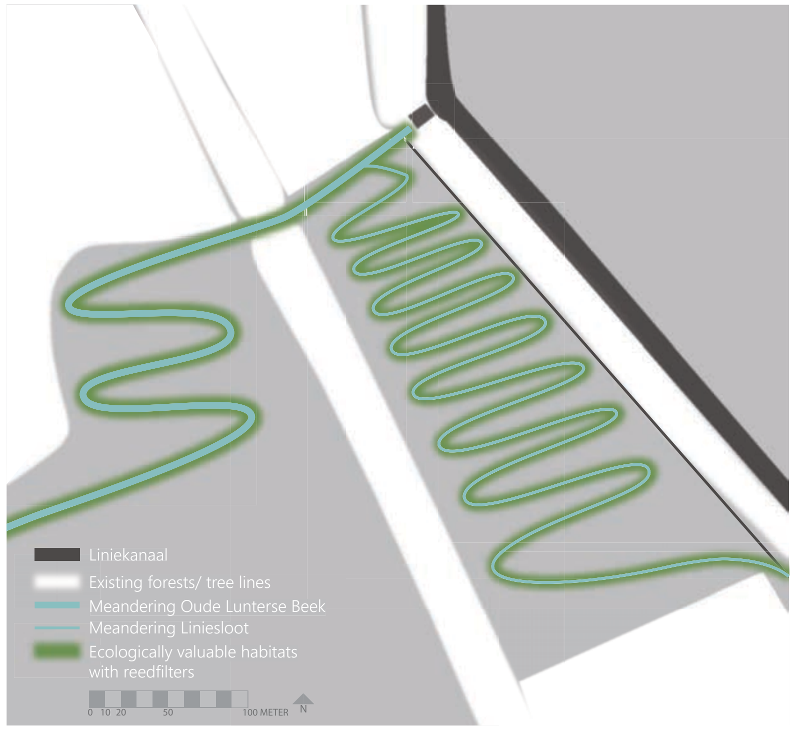

Figure XXa Concept drawing of the first model; creating a meander. Originally drawn on scale 1:1000.

MODEL II - PONDS

The second model (Figure XX b) is a set of pools instead of a stream. This has very big implications in a landscape point of view as the pools, water bodies, have other possibilities at the terrestrial level as the surface of the water will increase very much compared to a system with streams. This system should have a diverse function for the different pools, for water retention, sludge sedimentation, flea ponds and biotope ponds. The total mean residence time of this model is calculated at 2.30 days. The advantage compared with a stream is that the residence time is much longer, therefore the buffering power of this system is much better than other systems. Disadvantages are the landscape impact, the loss of faster flowing water streams and the implications regarding ground water systems and the dikes surrounding the plots.

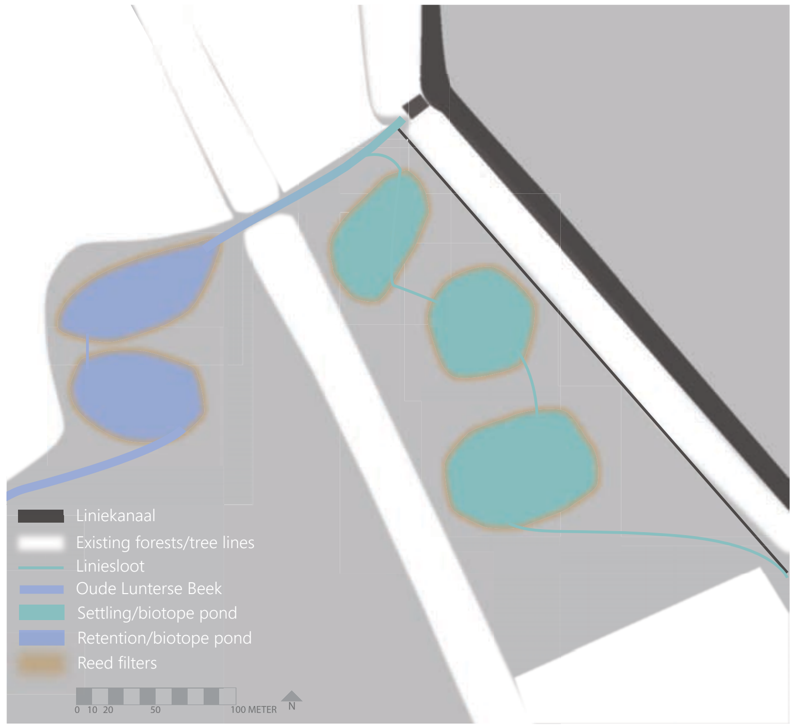

Figure XX b Concept drawing of the second model; creating a system of ponds. Originally drawn on scale 1:1000.

MODEL III - COMBINATION

The third model (figure XX c) is a combination of the previous models. The Liniesloot will be artificially meandering. The only difference between this meander and the previous meander (figure a) is the space for reed filters. These fields accommodate more water than the more natural meander, as the field around the stream are wider and the purifying function should be better as the residence time should be longer in these fields.
The Oude Lunterse Beek will change dramatically with the space of two large ponds. The ponds will function as biotope ponds and form the last connection between surface water and the waterharmonica. The ponds will be divided by a small dike with an overflow. This dike makes maintenance much easier and the overflow should enhance oxygen levels as the water drops.
The total mean residence time of this model is calculated at 1.78 days.
Advantages are the meandering stream with the possibility to make more diverse ecologically valuable habitats and the buffering power of the ponds.
The downside of those ponds is the landscape value of a pond versus a stream, whereby the Oude Lunterse Beek is a stream with value, not only in a landscape point of view but also from cultural heritage as the stream is older than most trees.

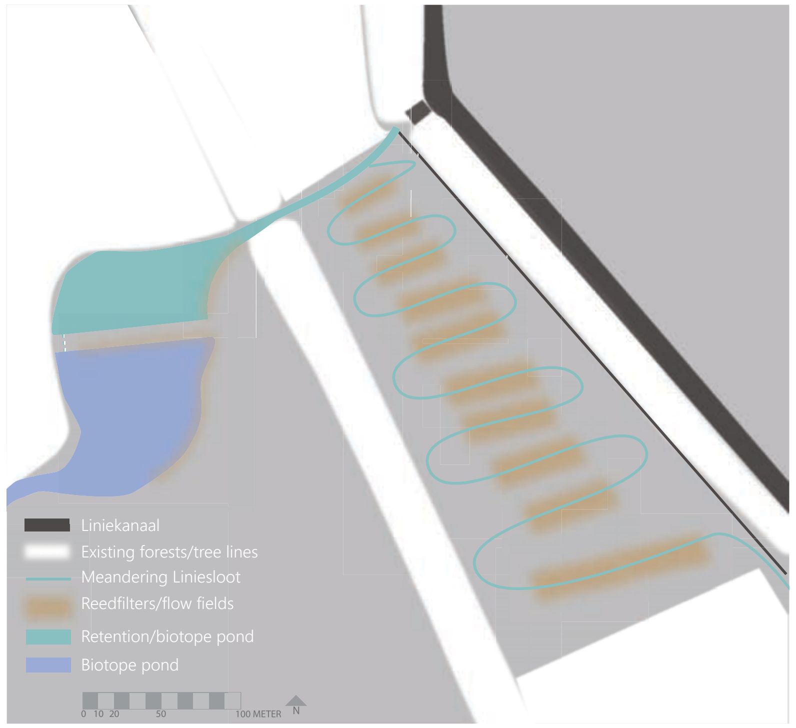

Figure XX c Concept drawing of the third model; a combination of a meander and two ponds. Originally drawn on scale 1:1000.

8. SPATIAL CONCEPT

By looking back at the previous chapter where three models were shown, a proper solution can be chosen and the concept derived from that model.
The base of the assignment is water purification; therefore, this is the first criteria for choosing the model. The second should be the presence of ecologically valuable habitats as the plots are property of Stichting De Boom. The last but surely not least is the suitability of the solution in the current landscape. Not only from aesthetic point of view, but also functional and hydrological perspective.

Based on water purification, the combination model is preferred as it combines more parts of the water harmonica and accommodates the water even compared to the other models.
Which model has the best opportunity to accommodate ecologically valuable habitats, is very hard to answer. What is known, is that the waterharmonica's are mostly mono cultured production fields of reeds and plants with the sole purpose to purify the water. More diversification in the system is desirable. The system with the combination of a meander and ponds seems, logically, the best solution as it diversifies. But, ecology around streams, aquatic as well as terrestrial, is very valuable as shown in the chapter ecologically valuable habitats. Therefore, the meander is preferred as it should have the most ecological potential of the three models.
The third of the criteria, suitability in the landscape, can be motivated by the landscape analysis. That concluded that the plots are very self-centred because the border is largely formed by high trees. Also, the possibility for overview is given in the form of the railway dike and the Liniedijk. But where the landscape analysis starts, with the Grebbelinie, is the most important regarding the change in waterbodies. As the inundation zone of the Grebbelinie was located at the east of the Liniedijk (figure XIX, p. 15), the west was the land that was defended. Therefore, it could be strange if the projection of the defended land is full of waterbodies. People could be confused which side of the dike is the inundation field, destroying a highly valued landscape element that defines the landscape along its 60-kilometre long system of dikes.

Another very valuable point from the landscape analysis is the ground water level, which is very high therefore the effluent will mix in streams and ponds, but especially in the ponds, the possibility exists that the ponds will be filled by groundwater and the effluent flushes straight through.

Choosing for the most suitable solution, motivated by these criteria should be the meandering option. But, that has disadvantages as well, therefore these should be changed. There should be more space for reed filters in flow fields along the stream between the corners.

SPATIAL CONCEPT

Starting to form the spatial concept, the idea of the waterharmonica has to be adapted to one, meandering stream with reeds and flow fields. To chose what type of meander it should be, 2 extremes are examined (figure XIa+b). This would either be a very constructed looking, controlled meander, or a free, natural flowing meander. As stated in the objective (p. 6), a goal is to enhance ecological value, therefore a natural solution is logical. A note has to be added however; the corners in the meander connecting the flowfields, have to be controlled, insuring a workable flow field system.
Important to consider is the flow rate in a meandering stream as the flow rate of a reed filter or a pond is very straight forward with one inlet and one or more outlets. In a meandering stream the flow rate between the inner corner and the outer corner can vary very much (figure XXII) and the corners will move as the outer corner erodes and the inner corner is getting sediment (figure XXIII). But the water flow between the corners should be constant, certainly as the flow fields can be designed in such a way that the water is divided evenly.

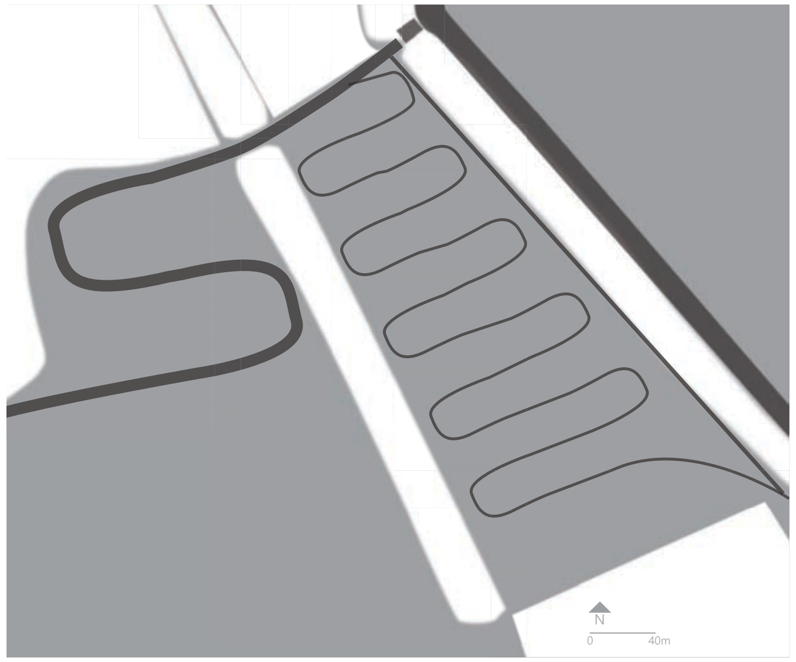

Figure XXIa Concept drawing of a constructed, fully controlled meander

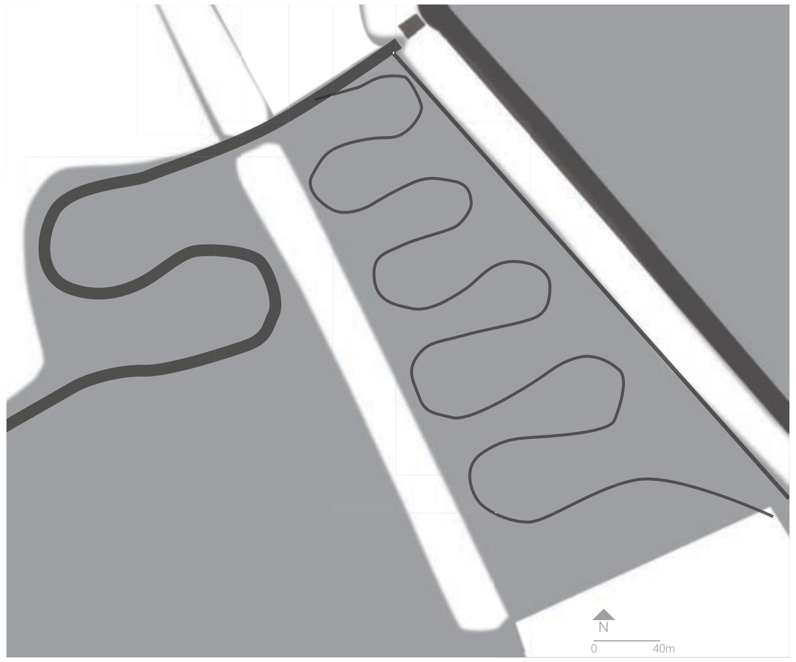

Figure XXIb Concept drawing of a natural, free flowing meander

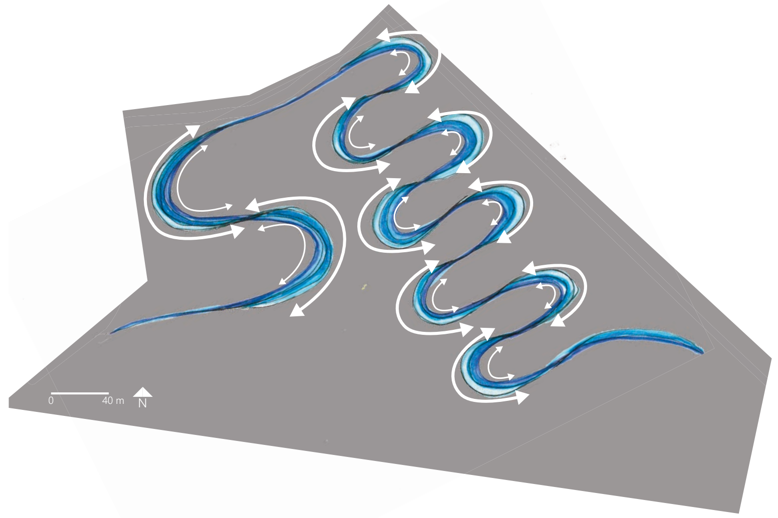

Figure XXII Concept drawing of a constructed, fully controlled meander

Figure XXIII Sedimentation in the inner corner of the Groote Beerze, waterharmonica Hapert, The Netherlands

The main concept map is very straight forward. As mentioned, the base of this design is water purification, therefore that should be the main point of the concept. Shown in figure XXIV, the spatial concept map starts with effluent straight from the sewage treatment plant and by flowing through the system, it purifies, the color is getting more natural and the biological life in the water will be enhanced.

What is shown in the concept map immediately, is the difference between the inner- and outer corner of the meander. The inner corner, where the bank would be more gradually building because of sedimentation, inhabits other flora and fauna than the outer corner where the bank will be more vertical as erosion will occur. But, as noted, this could mean that the meander transports itself over the plots. Therefore, during peak discharges, there is an overflow at the beginning of the meander where water will flow via the existing Liniesloot straight to the Oude Lunterse Beek.

The meander west of the disused railway dike, is different than the meanders between the flowfields. The west meander is wider, as the Oude Lunterse beek is wider than the Liniesloot (figure XIX p. 15) This meander has a fully ecological value, therefore this meander can move, enhancing different species in flora and fauna and creating a dynamic habitat. Here, the difference between inner- and outer corner habitat will be very visible and the meander can transport itself over time and between seasons.

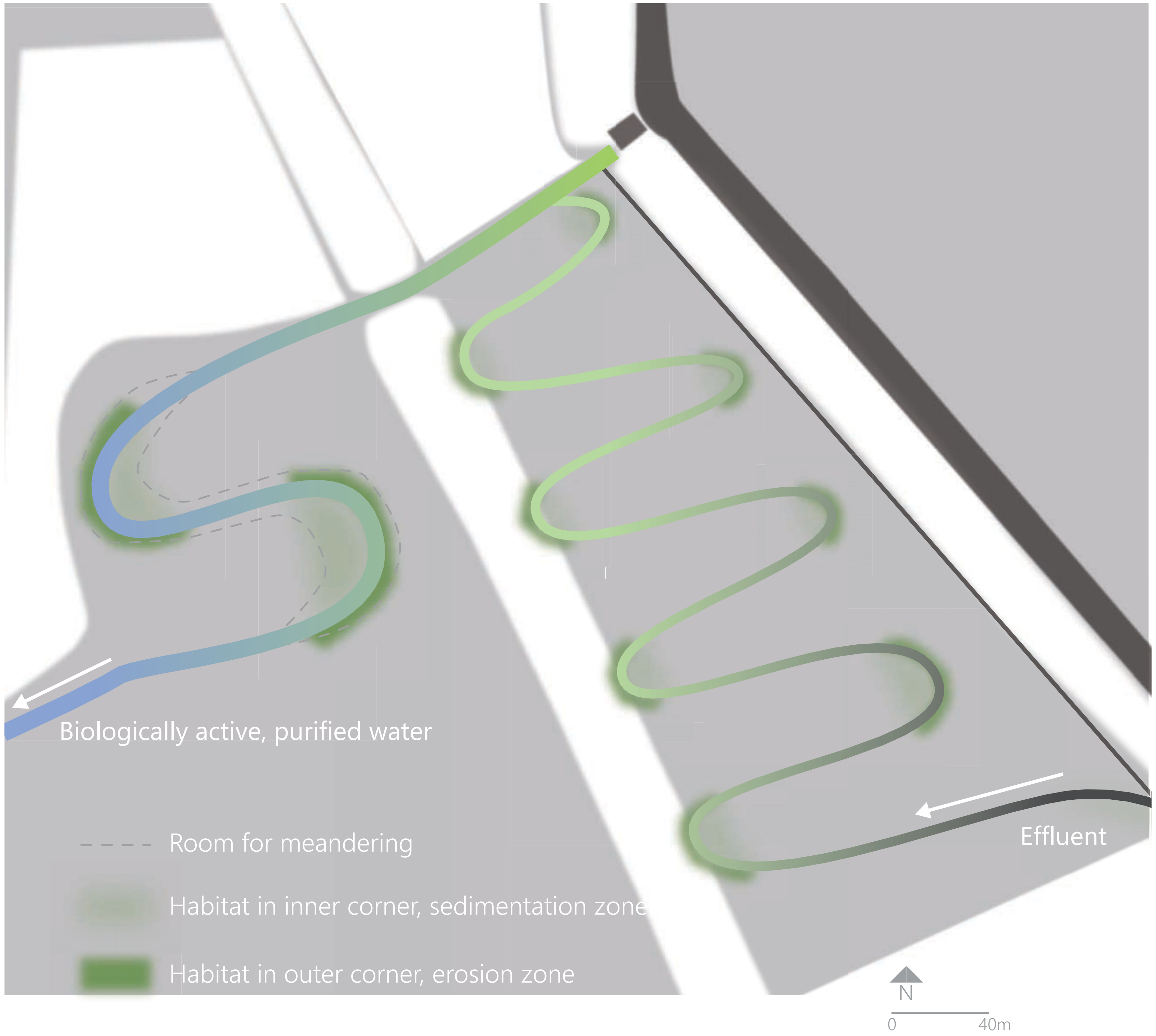

Figure XXIV Spatial concept map natural water purification

9. STRUCTURE MAP DESIGN

When structuring the design, the search started to look for the design that functions as a purification system, enhanced ecology and is future proof. Certainly with a meandering system, the stream got the possibility to move about as natural meanders move with the process of erosion and sedimentation, somewhat limited by the reed filters and other plants which keep the soil close in their root network.
The base of the structure map (figure XXVI) is the position and orientation of the meanders. After form studies, one shown in figure XXV, the number of meanders (8) and flow fields (8) is chosen, based on the surface needed for a functioning reed filter and the surface available on the plots east of the railway dike. The orientation of the meanders and straight parts are considered as well because that is important for an experience point of view, as the disused railway dike and Liniedijk are accessible by hikers. The meanders are closer to the disused railway dike than the Liniedijk, because of eventual high water and the risk of breaking through the banks of the stream. Therefore a buffer between the very valuable Liniedijk is maintained in the form of the Liniesloot which will only be filled with water during peak discharged.
Along the flowfields, trees (weeping willows, *Salix babylonica*) will be planted providing shadow in some part of the system. These trees could also bring in dead wood to reduce the flowrate and creating other aquatic habitats. The roots of these trees will also limit the amount of movement in the meander when eroding.

The disused railway dike, the Liniedijk and the Bruinenburger sluis will be left untouched in the landscape because of their historic value but also their ecological use as fauna will use the trees and create a more dynamic habitat, especially for birds and larger animals.

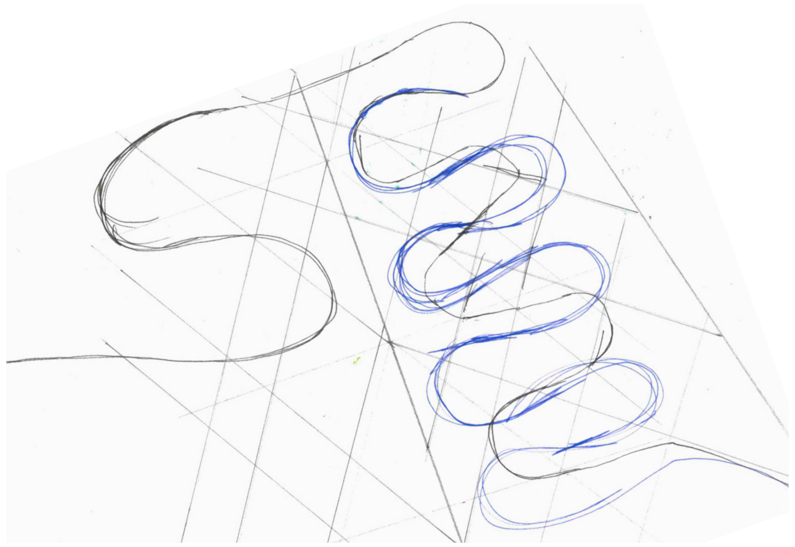

Figure XXV A form study to search for the right amount of meanders and the orientation.

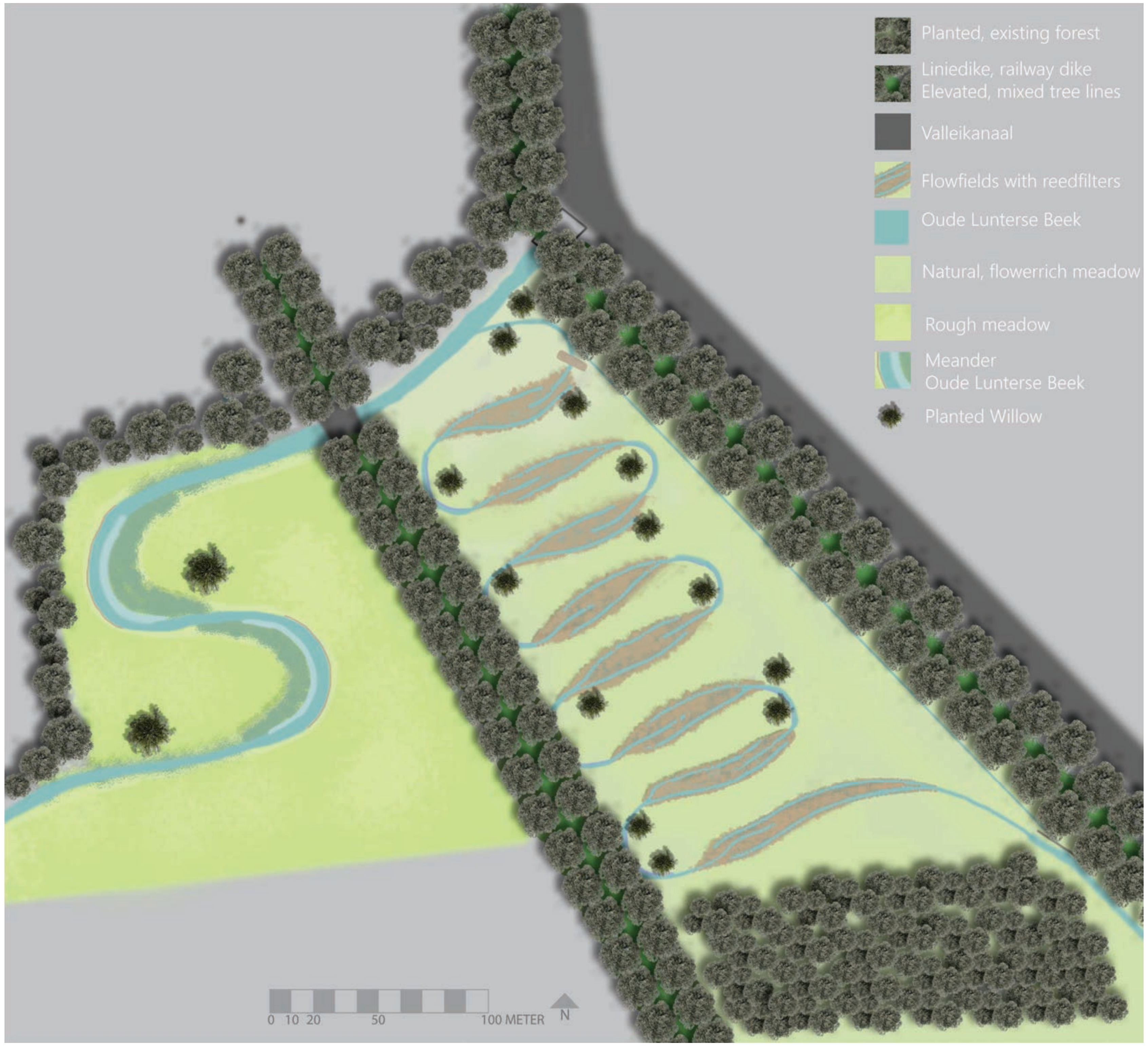

Figure XXVI Concluding structure map of the meanders with flow fields in between, inspired by the waterharmonica system. Originally drawn scale 1:1000.

The flowfield will work as shown in figures XXVII & XXVIII, two distribution channels distribute the effluent evenly over the flowfield and a discharge channel transports the water to the next flowfield via the meander (figure XXVI p. 19). The water flows out of the distribution channel via the helophytes, to the discharge channel. Because the flowfield is undeep but many times wider than the channel, the water flows much slower than in the channel, resulting a long residence time in the flowfield, giving the helophytes time to purify the water. The calculated mean hydraulic residence time of the water in the flowfields is 0.56 days, based on the cumulative volume of the flowfields and the discharge of effluent (figure IV p. 8).

However, this is the calculated time, and the calculated time compared with the actual residence time in another waterharmonica (Aqualân Grou) is different. This study in Friesland, Netherlands showed that the helophytes and stagnating corners in the waterharmonica, reduced the residence time up to 25% (van der Boomen, Claassen, & Kampf, 2013). This 25% of the waterharmonica has almost no flowrate, meaning that the water volume that is mixed with effluent is lowered. If this flowfield system has the same problem, we cannot say in advance, but what has to be taken into mind is that the calculated time can differ from the actual residence time, and that that can be up to 25%.

There will not be much biodiversity in the flow fields as there are only two species which can purify the water in the given residence time. That will be reed (*Phragmites autralis*) and cattail (*Typha latifolia*). If the flowrate in the flowfields is very low, duckweed (*Lemna minor*) will grow between the helophytes. This rapidly growing, free-floating plant has definitely a purifying effect, but the flowrate has to be very low for this to grow.
On the more shallow parts of the flowfields, the banks, more species will grow, but that is uncertain as local climate and seeds delivered by fauna also determine these species. A specie that is already growing in the wet parts of the plots, is common rush (*Juncus effusus*), a very common swamp plant.

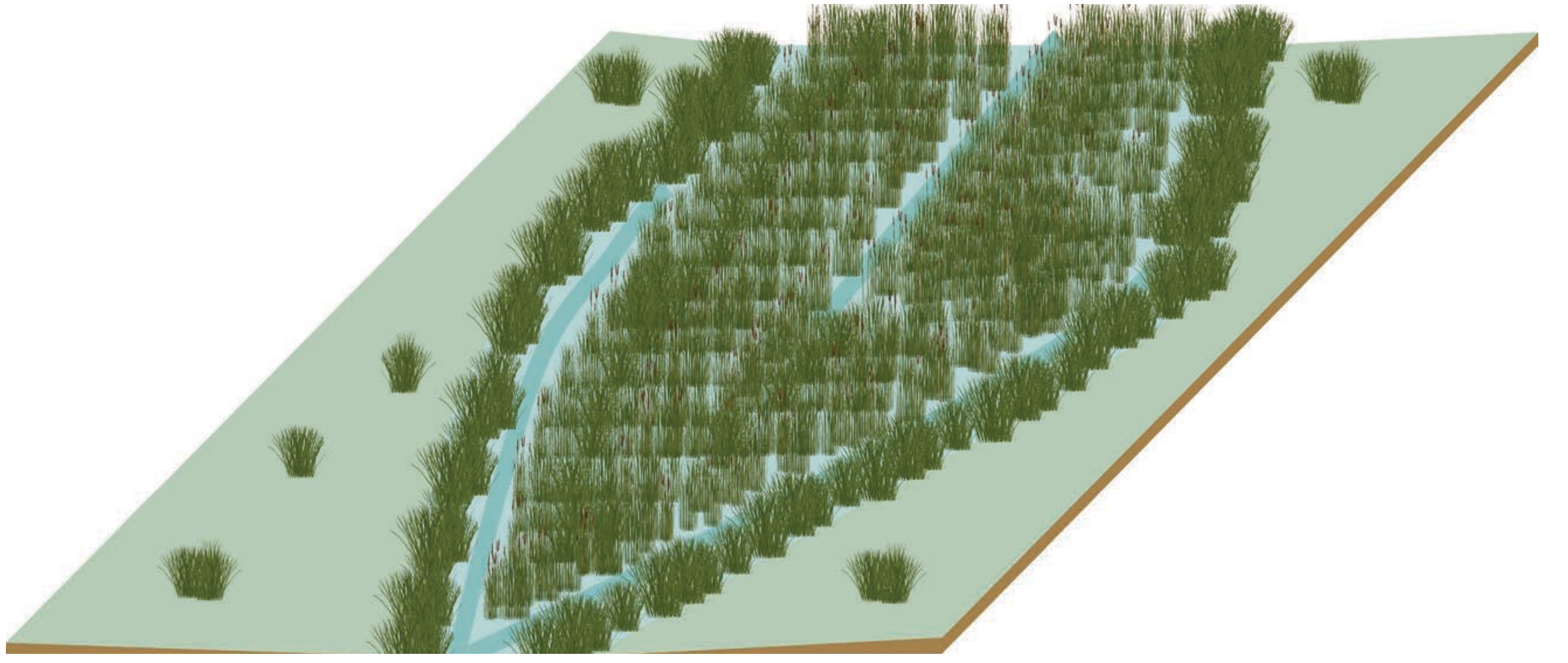

Figure XXVII Axonometric drawing of a flowfield displaying the principle of two distribution channels and one discharage channel. Originally drawn scale 1:100.

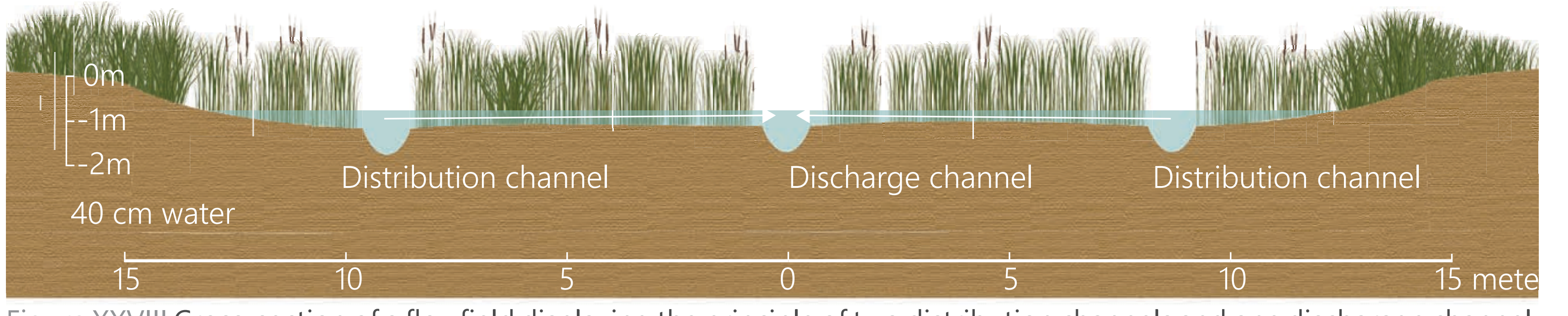

Figure XXVIII Cross-section of a flowfield displaying the principle of two distribution channels and one discharage channel. Originally drawn scale 1:100.

The meanders are designed and constructed but have a natural look and will be subjected to erosion, sedimentation and succession. Therefore, it is important to give the meander enough room to develop itself. As shown in figure XX the difference in height between the surface of the water and the bank a couple of meters away, is one meter. Because a wetland system (figure VIIIb p. 12) is used as the basis of the cross section for the meander connecting the flowfields, this space is needed.
On figure XIX we see the difference in vegetation near the water and further away from it, where the soil is less wet. In the dryer parts of the plots, grasses will predominantly grow. Species of the family *Poaceae* or *Gramineae* are the most common. Especially because these families of plants are very common for agricultural use, and because there are neighbouring agricultural plots, it will be likely that those grasses are going to be found on these plots as well. In the wetter areas, wild meadows with a variety of wild flowers, sedges, rushes and grasses will find their way. In the inner corner, a weeping willow is planted (*Salix babylonica*), as mentioned at the structure map.

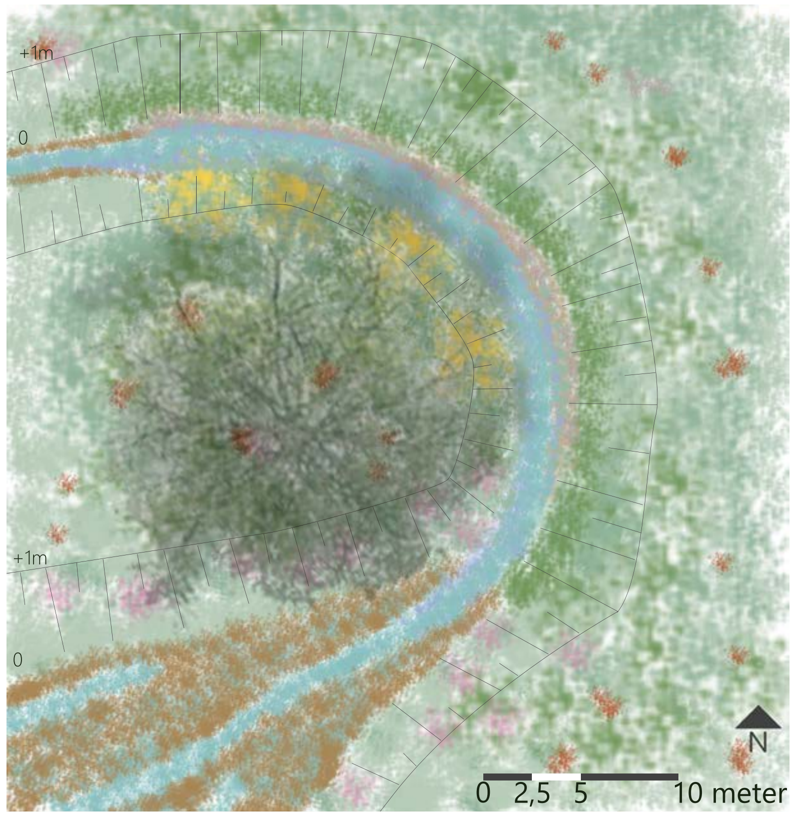

Figure XXIX Detailed map of a corner that connects two flowfields. The difference in vegetation is shown, based on the relief. Originally drawn scale 1:250.

The specific species however can vary much on the plots as the water is purified in the flowfields, therefore the fertility of the water decreases and that influences the habitat it creates on the banks. The logical assumption is that at the end of the flowfields, the water is less fertile therefore the species found there will be more pioneering species as the circumstances are rougher.

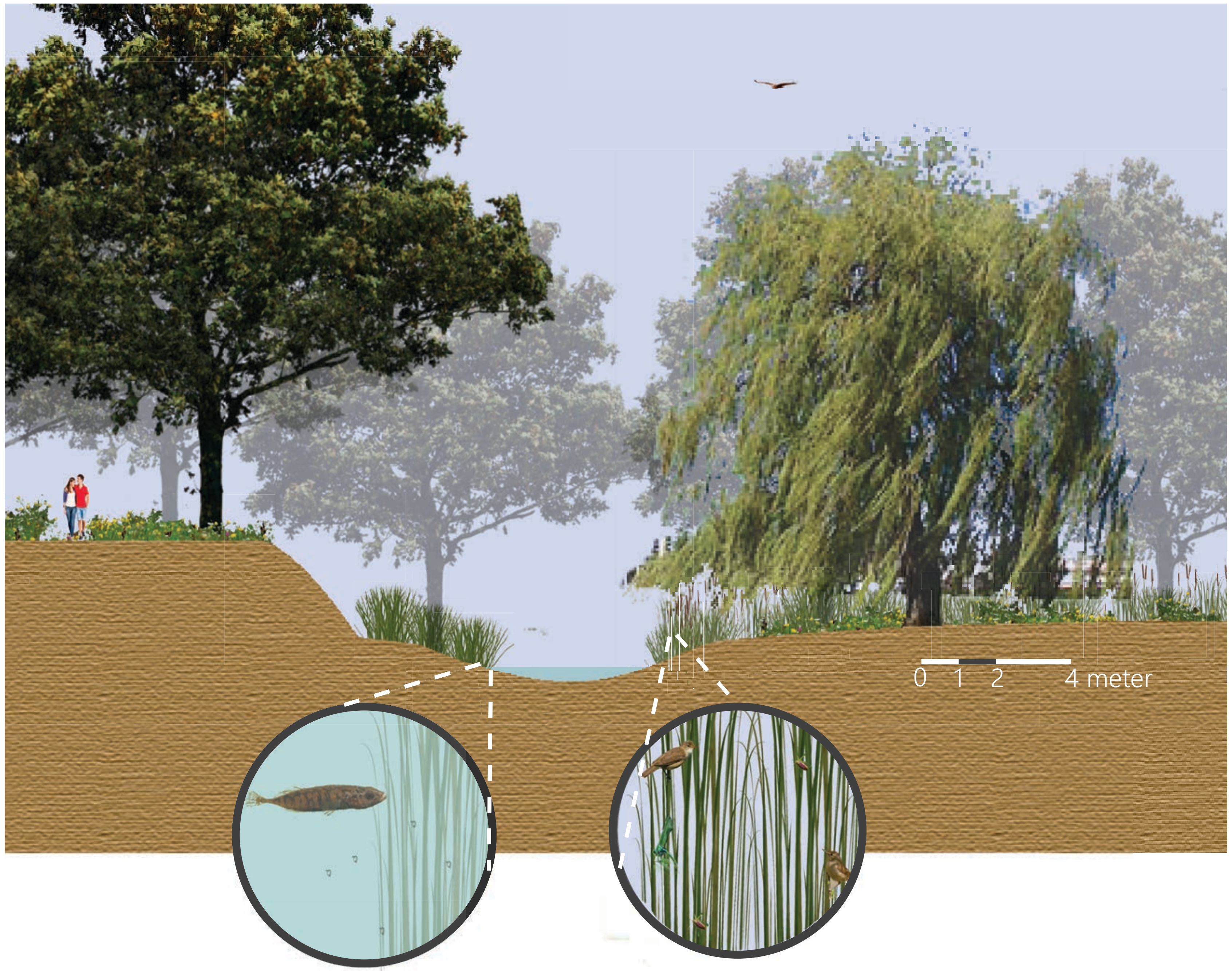

Figure XXX Cross-section of a corner in the meander near the disused railway dike (left). In the middle the stream with two blowups. The left is an example of the ecosystem in the water with sticklebacks eating waterfleas (from left to right). On the right blow up, some fauna that can be expected in the reeds like eurasian reed warblers, donacia reed beetles, the meadow brook jagannathans, and reed warblers (from top left to bottom right). In the sky an example of a predator, the marsh harrier, that forages on smaller animals. Originally drawn scale 1:100.

Between the two meander systems, the Oude Lunterse Beek crosses the disused railway dike. A bridge connects the two parts of the disused railway dike over the Oude Lunterse beek, as shown in figure XXXII. This detailed map with accessory cross-section shows the position of the bridge and relative height of the disused railway dike. The bridge seems over dimensioned compared to the Oude Lunterse beek below, but the situation of the stream given is during a constant, average waterlevel. During peak discharges, the waterlevel in the stream will rise, but the bridge will remain accessible and the trail on the disused railway dike can still be used. The current trail on the dike is shown in figure XXXI, and that differs from the road drawn in figue XXXII. The trail will be upgraded to a dirt road to ensure access to the flowfields by maintenance vehicles like tractors. When the road is not used by those vehicles, it gives clear idea of how the railway dike used to be, with one, clear sight to Woudenberg. The dike now is overgrown with bushes, not like it was when the railway track was present, and therefore dishonouring the railway dike. There are a few places along the long railway dike, outside of the project area, where the use of the dike is shown, but on this stretch of dike, the context is completely lost. That context is somewhat restored by recreating the long line of sight over the dike.

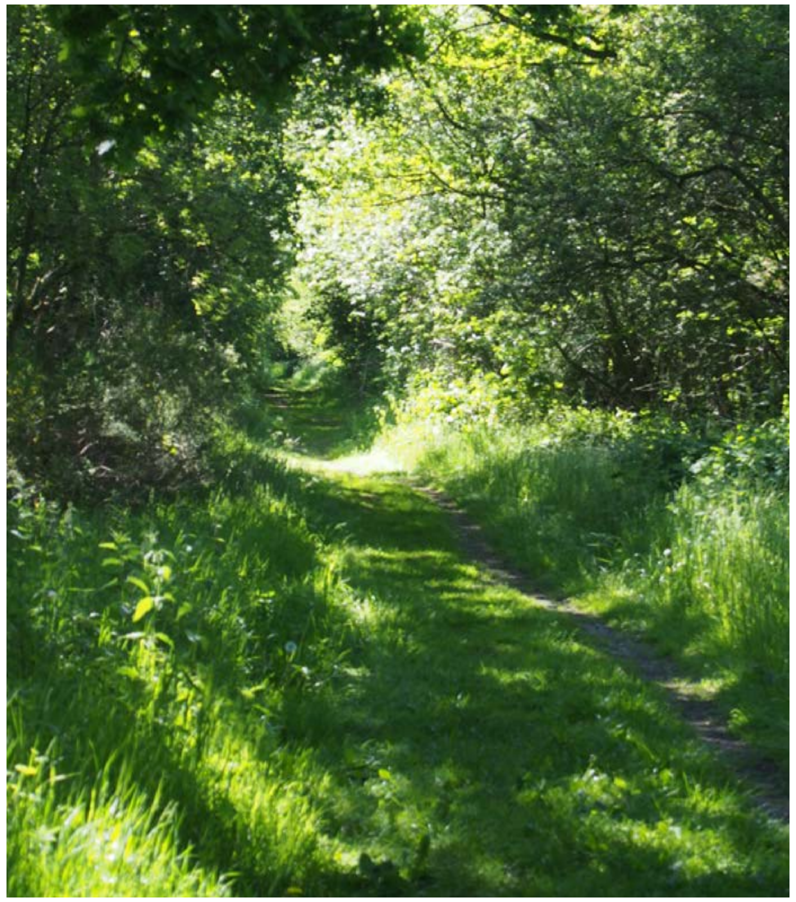

Figure XXXI Current trail on the disused railway dike, Woudenberg. Photo taken south of the bridge, looking south to Woudenberg.

The large, two cornered meander after the flowfields, is for ecological value, and not especially designed to purify, as mentioned. These meanders are given the space and time to develop and find their place in the ecosystem. The meanders are not present, therefore these are dug according to the cross-section shown in figure XXXIII (top). This figure shows the situation when it is dug and, below that, the situation after some time, when erosion and sedimentation are occuring. The light blue color shows the waterlevel during average discharge and the darker blue, is the projected waterlevel during peak discharges. The result of the rising water level, is that some plants dissolve under water, creating a dynamic habitat, necessary for attracting valuable flora and fauna.

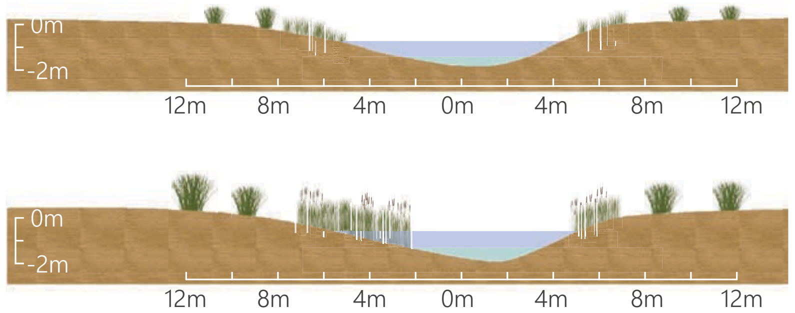

Figure XXXIII Cross-sections of the large meander. Originally drawn scale 1:100

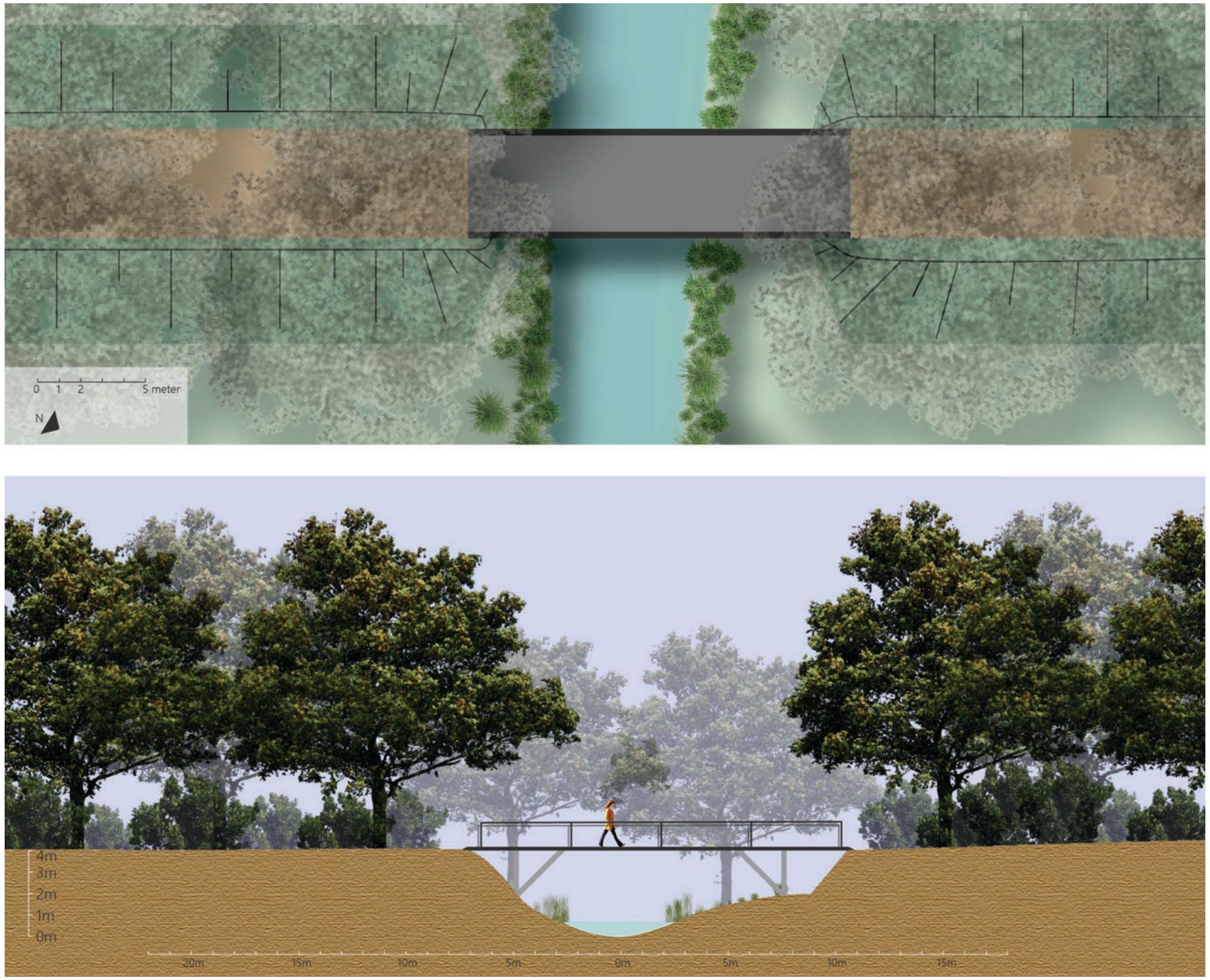

Figure XXXII Detailed map with cross-section of the bridge over the Oude Lunterse Beek, connecting the two meanders. Originally drawn scale 1:100

12. CONCLUSION

To conclude this thesis, all the answers to the questions asked in the beginning of report should be given in this report. The quality of the water discharged from the sewage treatment plant is cleared by examining the different compounds of the water and examining how biological active water is created from effluent.
How water is purified is explained in the chapter after that and methods are given how to do that. These natural water purification methods, inspired by the concept waterharmonica, are explained and the possibilities of application on the plots of the assignment are given. The combination of these water purification methods with ecologically valuable habitats are explained and what ecologically valuable habitats are, is explained, resulting in a clear set of requirements for the design.

With the models, the resulting structure plan and detailed designs, an answer is given to the general design question which is the most important in this landscape architecture thesis. The design question was:

How can a landscape design combine a natural purification process of effluent water with ecologically valuable habitats?

In short, that landscape design can be achieved by making a meandering system with room for flowing fields with reed filters. This solution makes the residence time of the water on the plots longer than it is now. The combination with the creation of a set of meanders, will give a lot of opportunity for ecologically valuable habitats. By designing enough room for water and nature, this system should be future-proof as well. This also answers most of the criteria of stakeholders in the area.

This thesis is based on two concepts; that of waterharmonica's and the enhancing of ecologically valuable habitats. Probably those concepts are not the only possible answers to the questions asked and the criteria given by the client and stakeholders. My personal view as a designer is explained in this report, but I am not an experience designer.

On of my personal biggest point of discussion is the view of the area and the surrounding landscape. Because this thesis is only 8 weeks long, there was no chance to see the plots regularly, for example in all the seasons. My view of the area is at a very specific point in time. Especially flora and fauna is very seasonal, therefore my view is limited. That probably will have an effect, not necessarily negative, on the design.

Another point of discussion is the applicability of this design in a cost-effective way. The costs of this project will probably be large enough for discussion, even though it is not cleared in this thesis. What is cleared, is the impact on the landscape but that does not pay the project unfortunately. This system does not pay for itself, it only costs money, especially with maintenance in mind; it is not self-sufficient making it harder to get all the money to make such a design.

Not all aspects of the design and its implications are cleared unfortunately, for example recreational use is only briefly touched upon, or maintenance, which is very important for the purifying system, has not been fully discussed.

PERSONAL REFLECTION

This thesis has been hard 8 weeks, but I am relatively content with the result; this report and the design. In the beginning of this thesis, I made some personal learning goals, one of which I am positive about. The expressive visualisations I made for this thesis, are the most photo realisic I ever made them during my bachelor. Handeling the scales however, keeps hard. For some reason I keep repeating the same mistakes I made in previous design assignements of not or wrongly applying scales in drawings and maps. That became especially clear after the final presentation (July 4th 2017) where was asked "where my design is". Unfortunately, that was also the first time during the thesis I heard I missed that step.
Looking back, I see I missed that step, probably because I thought I made that step in my head but it was not on paper. That could also be because of my lack in drawing skills.
The overall styling of the report including tables, small maps and diagrams, is however very like I imagined it to be. Very calm, completely in service of reading the report.
The key moment in this thesis was, in my eyes, the week with the visitation of reference projects; the waterharmonica projects in North-Brabant. There I saw how such a system looks in real life, and that of course is the goal in designing; creating something what people can experience and knowing how that looks and feels.
Therefore the theoretical and technical part in this thesis are the better part, the argumentation behind the design is, in my opinion, probably more clear than the design itself. Overall, I enjoyed doing this thesis, the assignment was interesting and very close to the real world as the assignement is a problem which needs a solution by the waterboard.

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FIGURES REFERENCES

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Figure XXXIII Author's drawing

TIMETABLE	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8
MA		PROPOSAL PRESENTATIONS	Analysis Elements	Landscape Analysis	MIDTERM PRESENATIONS	SUBMISSION DRAFT REPORT	Analyse Evaluation	Preparation Final Presentation
DI	BRAINSTORM GROUP & RUDI	Write Proposal	Design Elements	Landscape Design	Synthesize Designs	Re-apply Design Elements	Apply Evaluation	FINAL PRESENTATIONS
WO	Research	Write Proposal	Design Elements	Landscape Design	Synthesize Designs	Re-apply Landscape Design	Apply Evaluation	Finalize Report
DO	Research	Write Proposal	Design Elements	Site Design	Synthesize Designs	Re-apply Site Design	Visualisations	Finalize Report
VR	Research	Fieldtrip Woudenberg SUBMISSION PROPOSAL, LEARNING GOALS, PORTFOLIO	Design Elements	Site Design	Finalize Draft Report	Re-apply Sythesis Designs	Visualisations	FINAL SUBMISSION REPORT
Analysis-Sythesis Model	RESEARCH & PROPOSAL		DESIGN	APPLICATION	SYNTHESIS	EVALUATION	APPLY EVALUATION	VISUALISATION
Expected Deliverables	Thesis Proposal & Portfolio Report Fieldtrip		Design Elements Scientific Validation	Landscape Design Site Design	Synthesized Design Draft Report	Applied Results Evaluation	Applied Evaluation Visualisations	Final Presentation Final Report

APPENDIX A

APPENDIX B

SOERENDONK

In 2012, sewage treatment plant Soerendonk was completely redone, including the installation of a waterharmonica. The final station in the sewage treatment plant is a sandfilter, a similar system which is the final station at Woudenberg's installation. The waterharmonica is considered a success as a diurnal oxygen pattern noticed and in and above the water, biological life thrives. There also is a removal of chemical compounds and nutrients found. Metals are removed, buffered, as the water flows through the waterharmonica. Phosphor concentrations are clearly removed and bacterial concentrations are lower at the end of the waterharmonica. Also a noticeable amount of sludge collected on the bottom of the flea- and biotope ponds. That would be because there is a bypass at the sewage treatment plant during peak discharges. Therefore the water would not run through the sand filter, but the ponds collected the undissolved particles preventing the sludge from ending up in the Buulder Aa, the stream where the water is discharged in after it went through the waterharmonica. The dimensions of the waterharmonica are shown in figure B I.

The waterharmonica along the Buulder Aa functions too as a stepping-stone in the local small scale stream valley ecology. There are flower rich fields developed and fish steps in the pond. The biodiversity decreased as not all the plants can grow on the very nutrient rich soils and water.
Around the waterharmonica are no fences, only the water and tree lines devide the landscape from the waterharmonica. The waterharmonica therefore has a recreational function with information signs to give insight in the purification process. (Fleskens, Matte, & van Zanten, 2016)

The waterharmonica works as follows: The water flows via the final station of the sewage treatment plant, the sand filter (figure B II, 1), to the flowformcascade (figure B II, 2). In the flowformcascade, the water 'dances' around, bringing it in contact with oxygen. After that the effluent discharges in the flea ponds (figure B II, 3). Fleas eat the undissolved particles, thereby purifying the water. The next step in the purifying process are the reed/swampditches (figure B II, 4). Reeds and free-floating plants purify the water by taking up nutrients and metals and develop the biological life in the water. The final part between the surface water and the waterharmonica is a biotope pond (figure B II, 5). Via a fishtrap (figure B II, 6) the water can flow freely and the fish can migrate safely between the Buulder Aa and the waterharmonica.

Dry weather discharge	Design: 350 m³/u, average 7.780m³/d
Rain discharge	1.830 m³/u
Effluent quality	Total N: 5.5, Total P: 0.51, Undissolved particles: 6.2 mg/L

Waterharmonica Soerendonk (data dry weather discharge)	Surface (m^2)	Volume (m^3)	Residence time /d	Depth (cm)
Flea ponds	6.900	7.500	1,5	140
Reed/swamp ditches	15.000	7.500	1,5	40-60
Biotope ponds	6.250	5.000	1	ave. 125
Total	28.150	20.000	4	

Figure B I Table with the data of waterharmonica Soerendonk (Fleskens, Matte, & van Zanten, 2016 & author's adjustments)

Figure B II Birds-eye photo of waterharmonica Soerendonk. The systems are described in the text. (Fleskens, Matte, & van Zanten, 2016)

HAPERT

Back in 2001, when the sewage treatment plant of Hapert needed a renovation, the waterboard De Dommel made a swampforest as an after-purification to help maintain the blauwgraslanden (type of wetland) called De Levende Beerze. The waterharmonica inspired system was designated to be the missing link between sewage treatment plant discharging effluent and natural surface water flowing to the valuable wetland. The effluent contained too much nutrients and minerals which would harm the wetland. The sewage treatment plant in Hapert was renovated and given a spectacular look, bright red buildings, the plant was clearly visible and part of the landscape. That was a change in thoughts, sewage treatment plants usually are discrete, but this is not. That idea was continued in the waterharmonica, it is fully accessible for hikers and gives insight in what happens at the waterharmonica.

The swampforest can accommodate 40.000 m3 water, so during peak discharges, the water flows directly from the sewage treatment plant to the swampforest via a buffer ditch. This prevents overloading the helophytes. Because the workload of this system is very high, the residence time is low and the purifying plants cannot do their proper work. Therefore, the expected removal of N and P is not happening; the most use of this waterharmonica is the nature development. Together with the stream valley landscape of De Beerze, this landscape is very valuable for all types of nature, but the effluent is not spectacularly cleaned. (Fleskens, Matte, & van Zanten, 2016)

This waterharmonica works as follows: The water is distributed over two parallel systems, the northern system receives 60% of the discharged water, the soutern systems receives only 40% of the water. In normal circumstances, the water flow to a buffer ditch (figure C II, 1) to a similar dimensioned distribution ditch (figure C II, 2). The distribution ditch evenly distributes the water to two, parallel ditches with helophytes (reed) (figure C II, 3). In these ditches, the water is purified by plant uptake and biological activity in the water is enhanced. In the soutern system, the water flows directly to a swampforest (figure C II, 4) after it is treated in the ditches with helophytes. In the northern part the water flows via a (retention) pond (figure C II, 5) to the swamp forest. In the swampforests, the diurnal oxygen patterns are created, biological activity even more stimulated and the water is ready to flow into the newly constructed meander of the Beerze (figure C II, 6).

Dry weather discharge	Design: 718 m^3/u, average 8.000 m^3/d
Rain discharge	9.723 m^3/u
Effluent quality	Total N: 5.5, Total P: 0.31, Undissolved particles: 4.2 mg/L

Swampforest	Surface (m^2)		Volume (m^3)		Residence time /d		Depth (cm)
	North	South	North	South	North	South	
Helofytes	7.990	4.750	3.200	1.900	0,7	0,6	40
Ponds	7.670	-	10.200	-	2,1	-	133
Swampforest	2.160	2.620	600	600	0,1	0,2	25
Sub total	17.820	7.010	14.000	2.500	2,9*	0,8**	
End total	24.830		16.500				

Figure C I Table with the data of waterharmonica Hapert (Fleskens, Matte, & van Zanten, 2016 & author's adjustments)
* This residence time is achieved in 56% of the winter and in 59% of the summer.
** This residence time is achieved in 59% of the winter and in 70% of the winter.

Figure C II Birds-eye photo of waterharmonica Hapert. The systems are described in the text. (Fleskens, Matte, & van Zanten, 2016)