FLOODSCAPE

Graduation report by Michiel van der Drift

TU Delft

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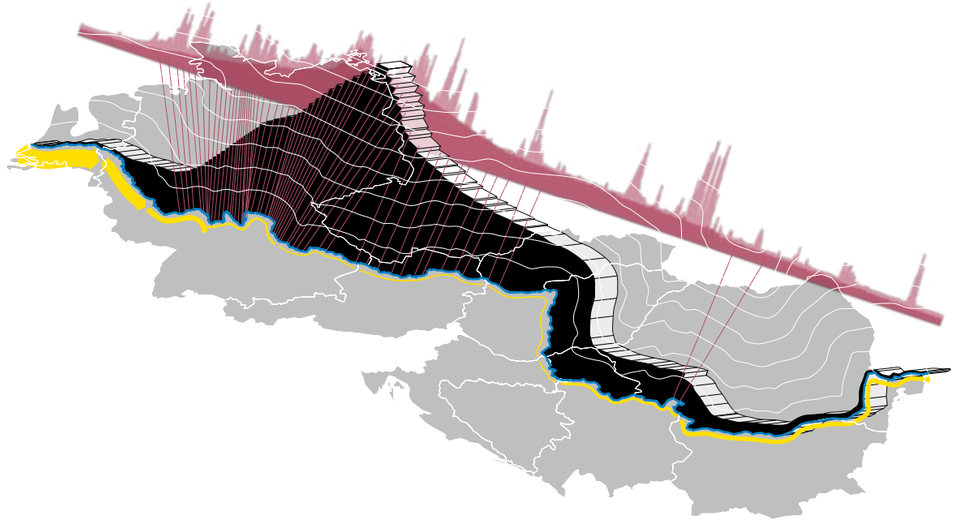
Preface

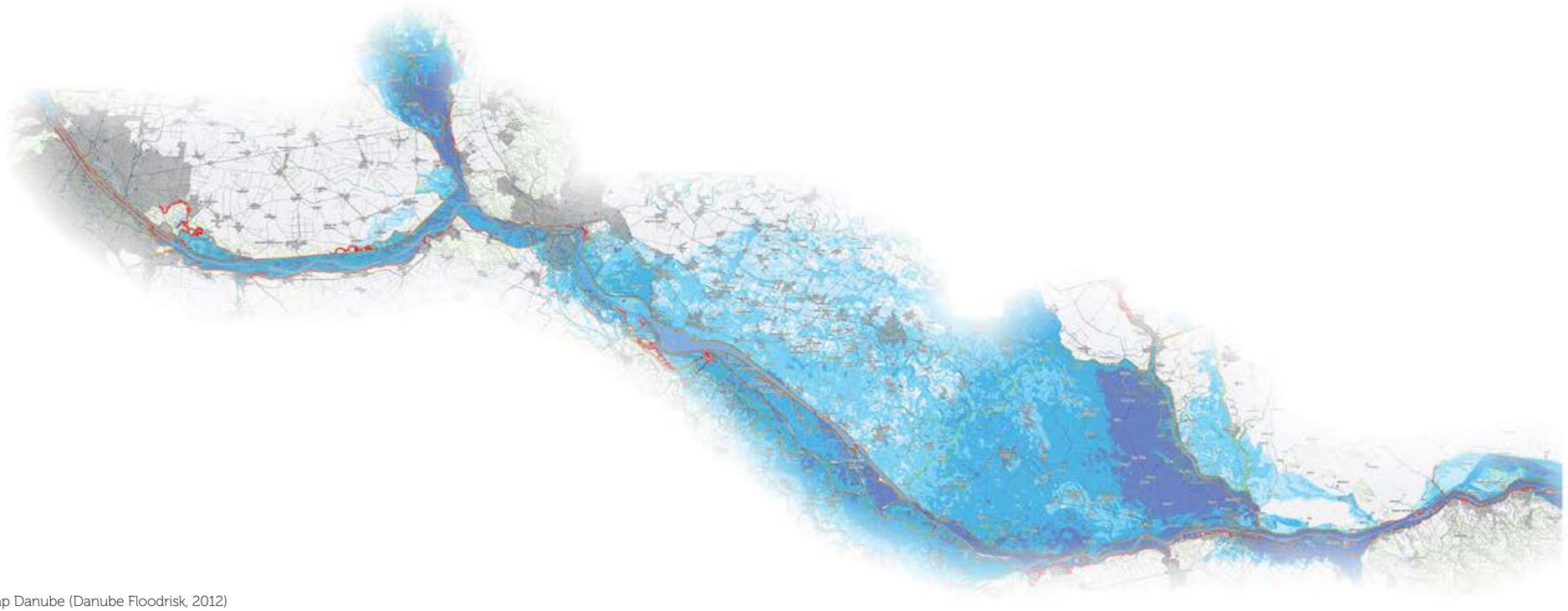
This report is part of the TU Delft MSc Landscape Architecture graduation project in the Graduation Lab Flowscapes; infrastructure as landscape, landscape as infrastructure. The report gives an insight into the information used during the graduation project Floodscapes. In February 2013 I started with this project and have since visited Bratislava two times, where I made many new contacts, both inside and outside the professional field. I still often have contact via mail or Facebook with some of them. With this project I revisited my time as a Bachelor in Civil Engineering by taking on a river project, but this time with the perspective and added knowledge as a landscape architect.



First mapping of Rhine/Danube Flowscapes Studio (Own Illustration, 2013)

Danube floods Bratislava, June 2013 (Google.com, 2013)

Photo of Danube flowing through Bratislava (Flickr.com, 2014)

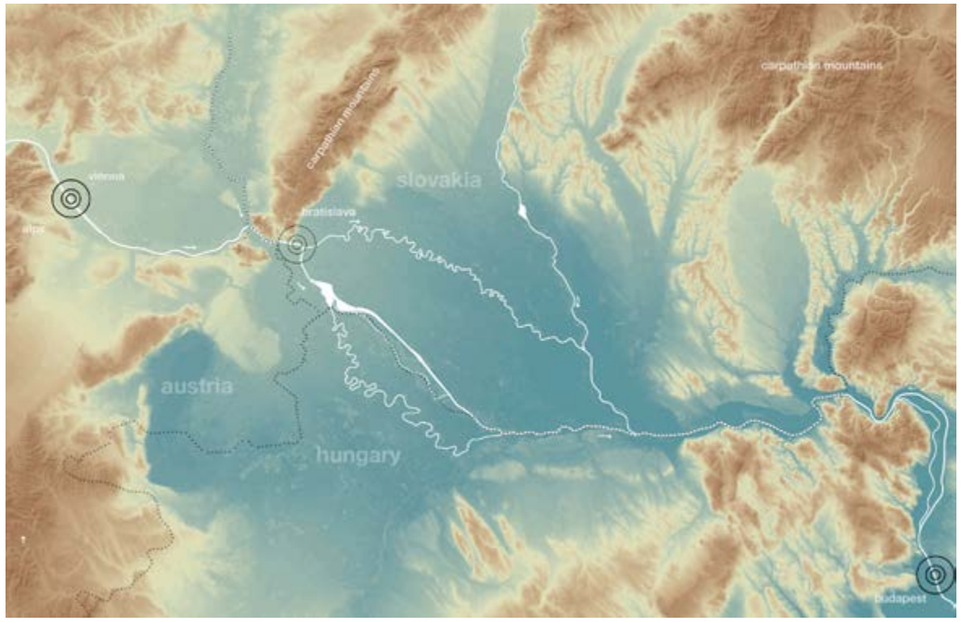


Floodrisk map Danube (Danube Floodrisk, 2012)

1. Introduction

The project location is the region of Bratislava, the capitol of Slovakia, which lies along the Danube just east to the border with Austria. The Danube flows from the Alps and passes the Carpathian Mountains, which lay north of Bratislava. Downstream of Bratislava the Danube flows onto the Little Hungarian Plain, covering parts of Slovakia and Hungary where the Danube slows down and splits into three different flows creating an inland delta. This inland delta contains one of the largest groundwater bodies of central Europe. Throughout time this delta was a very dynamic landscape, it was here where the river changed from a river running in a narrow valley through a mountain landscape to a river flowing freely in this large inland plain. It would often find a new path to flow through during a flood creating an interesting dynamic flood landscape with a wide floodplain full of alluvial forests and oxbow lakes (old river arms). Because of manmade interventions like dikes and dams the river has no longer a wide floodplain or the potential to diverge its course, changing the natural dynamics. In the current situation the river acts largely as a channel after it passes Bratislava.

Recent heavy rainfall upstream in Austria and the Czech Republic resulted in record high water levels of the Danube in Bratislava and other areas along the Danube. Parts of Bratislava flooded and the in the 2010 finished concrete flood protection wall in Bratislava was put to the test. This concrete wall was constructed with EU funding after a flood in 2002 and lies between the river and the city centre.



Elavation map (Own illustration, 2014)

2. Methodology

2.1 Introduction

Designing is often a process where action follows thinking, first you contemplate about a certain design problem, you start drawing what's in your head and reflect on the drawings you've made. This process can continue in multiple cycles. Models are also used in a similar way, you think about what you want to achieve and you start working on a model. The same applies to writing; often people use it to better define their design problem or explain design decisions. But what if we combine these processes? What will we gain if we would stop thinking in our head and instead start the process with our hands? In this position paper I want to discover the different possibilities of designing by practice. Doing as a means of thinking. I will focus on three different main techniques; design by writing, design by models and design drawing. With all three I am interested in how they can be used as a tool rather a goal in itself.

Often I have the problem myself, that I keep thinking for to long and try to solve all the problems before I act, whether it is with drawing, writing or making models. I want to see if through this position paper I can better define some guiding principles that I can follow to get me to design by practice.

The position paper has a classical structure; chapter two will be a theoretical framework as a backdrop for the rest of the paper by using different literature. After that I will explore the different techniques illustrated by some relevant examples and my own experience. And the final chapter will be a reflection where I try to distil some meaningful lessons from the position paper.

2.2 Theoretical framework

Designers are not considered the archetypical researcher but when we talk about research we often mean the scientific method. While it is save to say that this isn't the only type of research. Ilpo Koskinen discusses this;
"We still hear talks about the scientific method, even though there clearly are many methods...In contrast, we argue that there is a need for many types of methods and methodologies..."

This means that even though most designers don't research using the scientific method, they are in fact researchers nonetheless. The tools we use are somewhat different. A designer is more inclined to use nonverbal modes of thinking and communication, such as drawings, diagrams, sketches and models and not the classical verbal, numerical and literary modes.[1]

You could say that the designer uses a different language when dealing with a (design) problem than for instance a scientist. Where a scientist often uses theory

1 Cross, 2006, p. 11

and calculus to distill the provided data into a solution, a designer simply doesn't have a system which can process data to end up with a design solution.[2]

These nonverbal modes of thinking can be seen as the outcome between a mental process and external expression, as stated by engineer-architect Santiago Calatrava: *"To start with you see the thing in your mind and it doesn't exist on paper and then you start making simple sketches and organizing things and then you start doing layer after layer... it is very much a dialogue."*[3]

This dialogue Calatrava is talking about shows that designing is a reflective process. You start sketching, writing or working on a model and while you are doing that you get a direct feedback that can trigger another response. This can continue for endless cycles.

2.3 Techniques

Design by drawing

Drawing is often the first choice for a designer to develop its thought process. Daniel M. Herbert[4] believes that "drawings are the designer's principal means of thinking". Graves[5] emphasizes that sketches are used as a "reference"; the starting point for further development of the thought process. From there the designer can use, add, transform or change the drawing in any form or shape. But to often in my own experience I am too preoccupied with the final outcome of the drawing that the process of discovery through drawing is lost. While this process is one of the most important tasks a designer ought to be doing. The journey is just as important as the final destination.

A designer has many different ways in which he can design by drawing but I personally think one of the more interesting techniques is the experimental drawing technique. Often it is a mix of collage, superposition and abstraction. One could for instance use a certain landscape element and use that as a building block. You force yourself to follow certain self-opposed rules to give you some guidance. This is a technique I often use in my own design, it is a great way to break through a stagnated thought process and force you to take action. A lot of times these exercises result in an interesting perspective on a design problem or show a new potential for the project.

I often am inspired by drawings that might not be considered beautiful drawings, you could even see them as dirty scribbles on a piece of paper. But those drawings show a certain process the maker is going through, it draws directly what it thinks and reacts on what it draws. Where often drawings have a supporting role in a story, with designing it is the other way around; the drawings can be the main characters. Catherine Dee writes "Some have been drawn to illustrate and idea formed during

2 Cross, 2006, p. 34
3 Quoted by Lawson, 1994
4 1993, p. 1
5 1977, p. 385

the process of writing, while at other times the need to write has emerged from the making of the drawing." This illustrates the undeniable link between writing and drawing, and certainly model making can be added to those two.

Design by writing

Writing as a design methodology isn't a very well developed or documented form of methodology. And although some great designers are skilled writers as well, it is often used as a presentation tool. It is either used to explain their design or to elaborate on their philosophy by writing an article, paper or book, which becomes the end product on its own. Rem Koolhaas is such a designer with his famous manifesto Delirious New York[6], staring the city of New York as a metaphor for the vast variety in human behaviour.

But using writing as a methodology during the design process is in my opinion not something that is considered mainstream in the field of landscape architecture.

"Because thought processes are dependent on language, every attack on prevailing linguistic forms ultimately enriches worn out modes of thought."[7]

I find this quote by Marjorie Perloff very inspirational, for me it shows the necessity of stepping outside the normal thought process. By trying new methods your mind will be challenged into discovering new territory, which I consider essential for someone like a landscape architect who works for a large public, effecting lives of many. It may sound elitist but as a designer I feel it is not only our task to build what people want but also discover what people need they weren't aware of.

But stepping out of our comfort zone and discovering new things is no easy task. We are very much programmed by all kinds of outside factors such as; where you were born and live, what kind of family you grew up with, your age, gender and sexual preference, your education or profession and many more factors. All these factors determine where our mind wanders, what connections we make and what we see as meaningful.

There are multiple writing techniques that can be used during a design process. You could divide them in two main categories; free associative writing and targeted writing. When choosing a technique you should be aware of the benefits and limitations between them.

6 Koolhaas, 1994
7 Marjorie Perloff 2010, p. 117

Free associative writing

This technique is derived from a method in psychological analysis, developed by Siegmund Freud and his colleague Josef Breuer.

"It has not been fully appreciated that psychoanalysis, in its origins, was both a talking and a writing cure. When Freud instructed his patients to say whatever came to mind, using words to verbalize that which was preconscious replaced the hypnotic technique as the "talking cure" and was the beginning of the psychoanalytic method. Freud used writing to an internal other in his self-analysis, and his free association writing has had an enormous influence on psychoanalysis." [8]

It is a method where you write all of your thoughts that come into your mind; the thoughts might be related or not where one word can lead to the next. It may or may not be possible to follow a pattern of thinking when practicing free association, which is ultimately the point of the practice. Generally, this method of analysis will begin with a word, phrase, or question, and the person will allow all the thoughts regarding that original word to come to the surface without censoring or analysing them. During different stages in a project I use a technique, which you can call free associative writing. This is a method where you put your pen on the paper and let your thoughts flow freely. While I am writing I react on the words that I wrote which may spark new ideas or make my ideas more focused.

Mind maps are a form of free associative writing often used in a brainstorm format, what can be done as an individual or in a group. Starting with one word, phrase or subject you can quickly develop associations, underlying issues or chances. Often these word clouds progress from big to small, where the starting point is broad, and were every step further becomes more and more detailed. This technique can point out the relevant issues, subject or chances in a very quick and practical overview. But sometimes this technique lacks the detail you might need for making the right decisions.

Target writing is a technique where you first start with a clear goal what to achieve or develop. Answering questions with a clear answer, reflecting on that answer and rewriting it if necessary. It has less to do with free association like the other two techniques but

8 Farber, 2005, p. 249

Design by models

Models are an essential tool in the design process and are often used by all kinds of designers. You can distinguish three phases in the design process where one could use the model; analyzing the existing situation, design generation or development and finally presentation.[9]
In the standard design process it is mostly a presentation tool, to show the audience how a design will look like after completion. But what I would like to advocate is using models in an early stage in the design process, as a tool to develop your thoughts instead of being a reflection of those thoughts. I will illustrate the use of models with three examples, chosen for their groundbreaking use (Gaudi) and the relevance in todays design landscape.[10]

In the current time models are mostly used to show the mass, proportions and the appearance of a building or public space.

"Models contain information and thus they play a role in communication, study and research. The focus of the exchange of information can be on the transference and broadening of knowledge but also to force action."[11]

Figure 2.1 Model construction research Sagrada Familia (Yi, 2007)

9 Nijhuis & Stellingwerff, 2011, p. 2
10 H+N+S Landschapsarchitechten and Neutelings Riedijk Architecten
11 Klaasen, 2002, pp. 183-184

But before the computer models where also used for other purposes, for example to explain a construction or as a guiding tool for building complicated geometric shapes. Gaudi, for instance, made many models for the construction of the Sagrada Familia in Barcelona.[12] Besides models to explain complicated geometric shapes he also made large scale models of certain details that are still being used today in the construction of the Sagrade Familia, 50 years after his death.[13]

Nowadays designers don't use models in the way Gaudi used them, it is becoming more and more a communication tool to explain the design to the client and user. One of the most import reasons for using a scale model is to define the scale of the project.

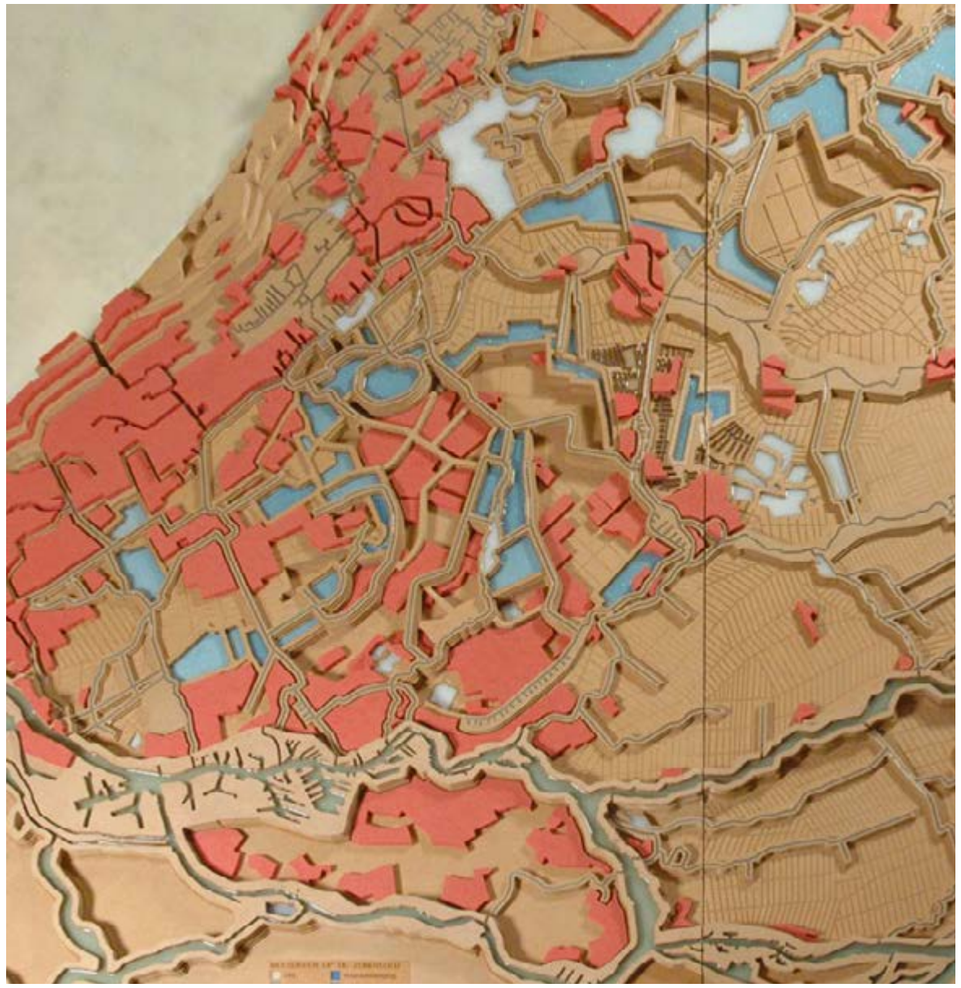


Figure 2.2 Model New Water system Randstad (Model and design H+N+S landschapsarchitecten)

12 fig.2.1
13 Watkins, 2009

"The architectonic scale model must be viewed as a mechanism to define, it mediates between chaos and human design. It is a mechanism that helps the designer to create an understandable scale which the unknown can be determined, like a future building."[14]

Abstraction is a very common tool in the design process, it is used on all different scales and media. Also in model making this is often used to discover new potential or emphasizing a certain element in the design. H+N+S made a model[15] for a design of a new water system in the Randstad, with a vertical scale making the height differences more apparent. By doing this it gives a new perspective on an interesting design. And although this model itself is a finished product, the process making it is a design research itself.

Another method using models is research by variants. This method is often used by Neutelings Riedijk Architects[16] where they make tens and sometimes a hundred different miniature models while the design a building. They make an endless array of variations[17]. They start from a free association or an abstract sketch from the lead architect. When, after the first round of models the base shape is decided upon that shape will be used as starting point for a new round of models until the desired outcome is reached. It is almost a form of sculpture making.

"That's why we work as sculptors; a building has to be slowly carved, freed from the Styrofoam blocks in our model room. We see the buildings as a fullness at first. A volume is after all a solid. By try after try, first a bulge to the left, than a cove to the right, and finally a nick on top, the shape slowly becomes the volume."[18]

In this process there is a lot of room for intuition, because of the rapid fabrication of models there isn't much time to think about decisions. As a designer you aren't held back by practical limitations, those will be solved at a later stage.

What I particularly like about the working with models is the direct interaction you have with your own work. An intuition based or unintentional change in the model can provoke a reaction that could become the start of your design. By being able to see the direct spatial implementations of your design changes you can come to quick decisions. You are in a dialogue with the model.

14 Smith, 2004, p. xxi
15 fig.2.2
16 2004, p. 8
17 fig.2.3
18 Neutelings en Riedijk, 2004, p. 10

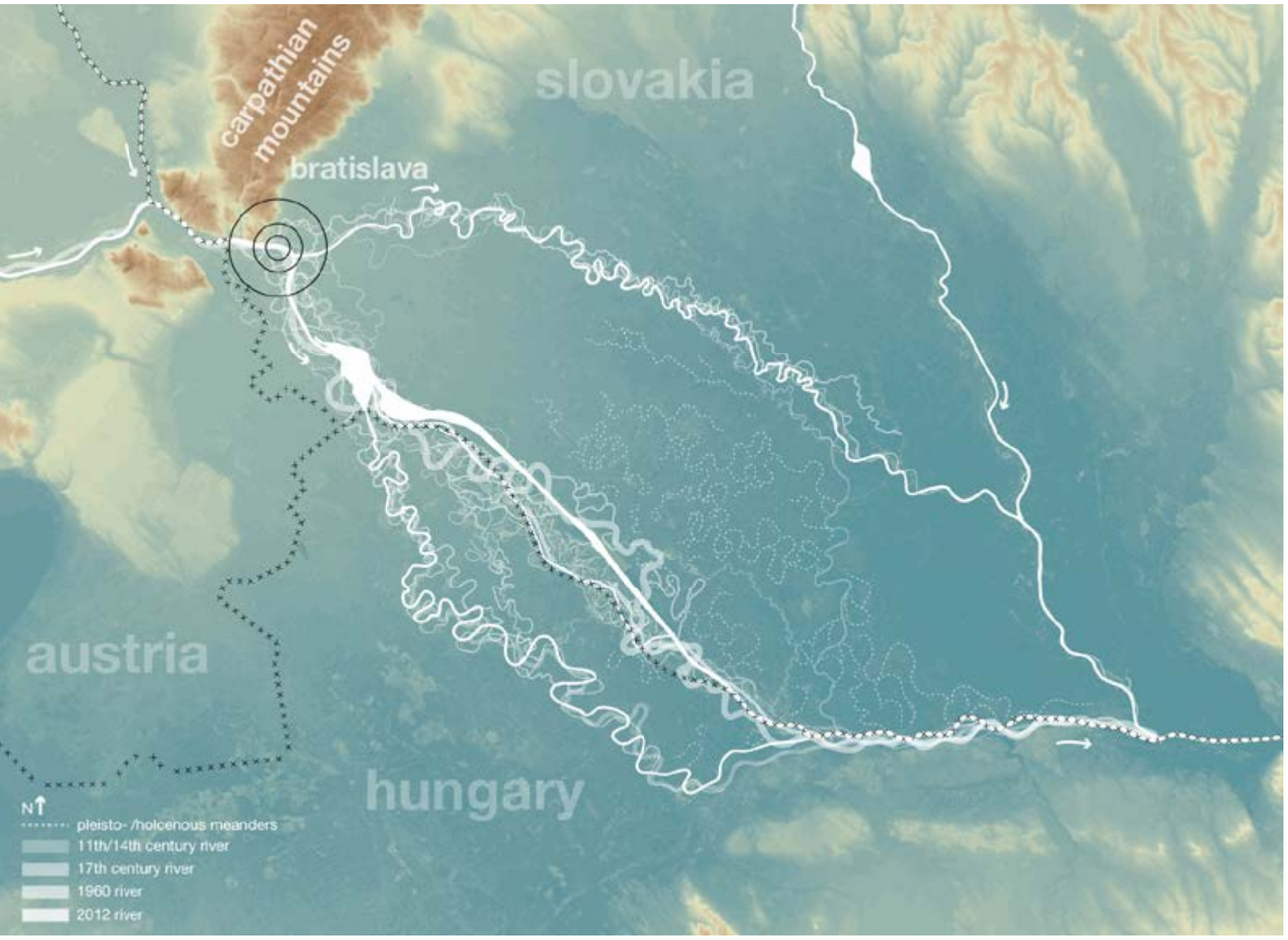
Conclusion

The act of drawing is often considered the primary means of a landscape architect to start its design but I would like to advocate that is the act of doing that is essential. No matter if you feel comfortable starting to make a model, draw a rough sketch on a beer coaster or write your own Freudian inspired flow of words, you just have to start. I think that will be my main lesson I take away from this paper and the literature I read. Too often I postpone the act of doing, going over the different possibilities in my mind while not doing anything.

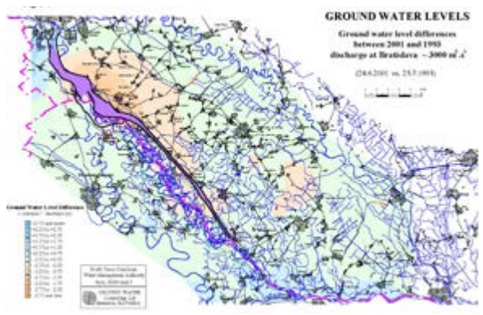
The postponing of moving from the problem phase to the solution phase was also perceived by Cross.[19] He noticed that this occurred more often with senior students than with the junior students who weren't considering all the possible problems and solutions.

Figure 2.3 Model research (Neutelings en Riedijk, 2013, schatkamer.nai.nl)

19 2006, p. 79



Juxtaposition of Danube throughout time (Own illustration, 2014)



Changing groundwater level (Gabcikovo.sk 2013)

3. Problem Statement

Gabcikovo Dam (Google.com, 2014)

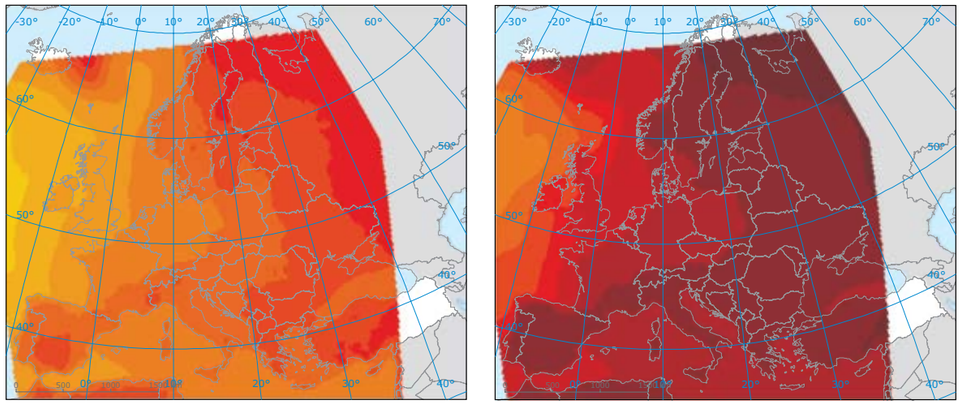
3.1 Normalization of the Danube

As mentioned before, the Danube used to be a very dynamic river with a wide floodplain. Throughout time the river became more and more normalized to accommodate transportation via ships and hydro energy projects like the Gabcikovo dam.[20] The landscape lost its natural ability to deal with the fluctuation of the river discharge.[21] One of the side effects of the normalization of the Danube and the loss of floodplain forests is an increased runoff speed of the Danube. Water travels faster downstream creating problems at bottlenecks, for instance narrow river valleys and urbanized areas (Vienna, Bratislava and Budapest e.g.). The floodplain forests were adapt to hold the water in place and feed it into the groundwater. The normalization of the Danube is the main reason why we see an increase in floods in the Danube basin. But not only flooding is a problem caused by normalization but also the effects of long periods of drought are intensified. When the river water has little time to recharge the groundwater because of the increased runoff time the consequences will become more extreme.

20 fig 3.1
21 fig 3.2

3.2 Climate change

Climate change is a topical issue. Its negative effects are constantly in the news and in the last few years' more and more innovative ideas and developments have come forth from research and climate ateliers to balance these effects.[22] There is an urgent need for new ways of thinking regarding the effects of climate change. Instead of focussing on solely on adressing the negative effects of climate change we could see it as an opportunity for future developments.



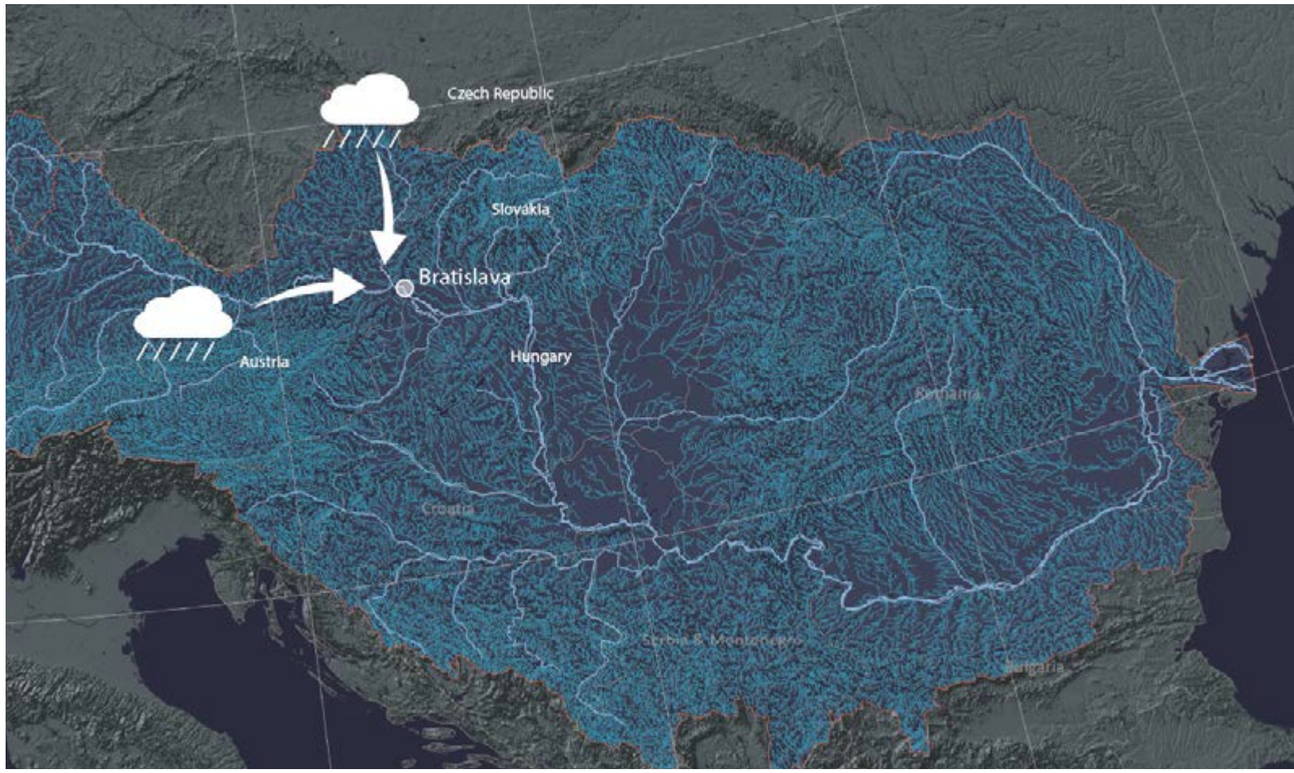
Projected changes in annual near-surface temperature 2021–2050 (left) and 2071–2100 (right)

0 0,25 0,5 0,75 1,0 1,25 1,5 1,75 2,0 2,5 3,0 4,0 5,0 ° Celcius

Temperature rise in Europe (eea.europa.eu, 2014)

The rise in average annual temperatures[23] will have an increasingly large impact on the rivers hydrology. Floods will occur more often in the future caused by extreme periods of precipitation. The last few decades the occurrence of high water levels of the Danube caused by extreme rainfall in Germany, Austria and the Czech Republic has increased.[24]

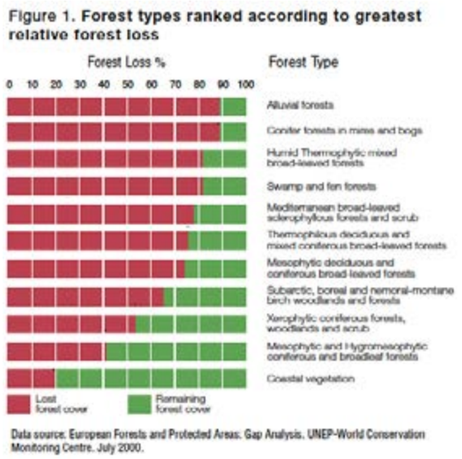
22 de Pater et al., 2011
23 fig 3.5
24 Pekarova, 2013



Extreme rainfall (S. Nijhuis et al, 2012)

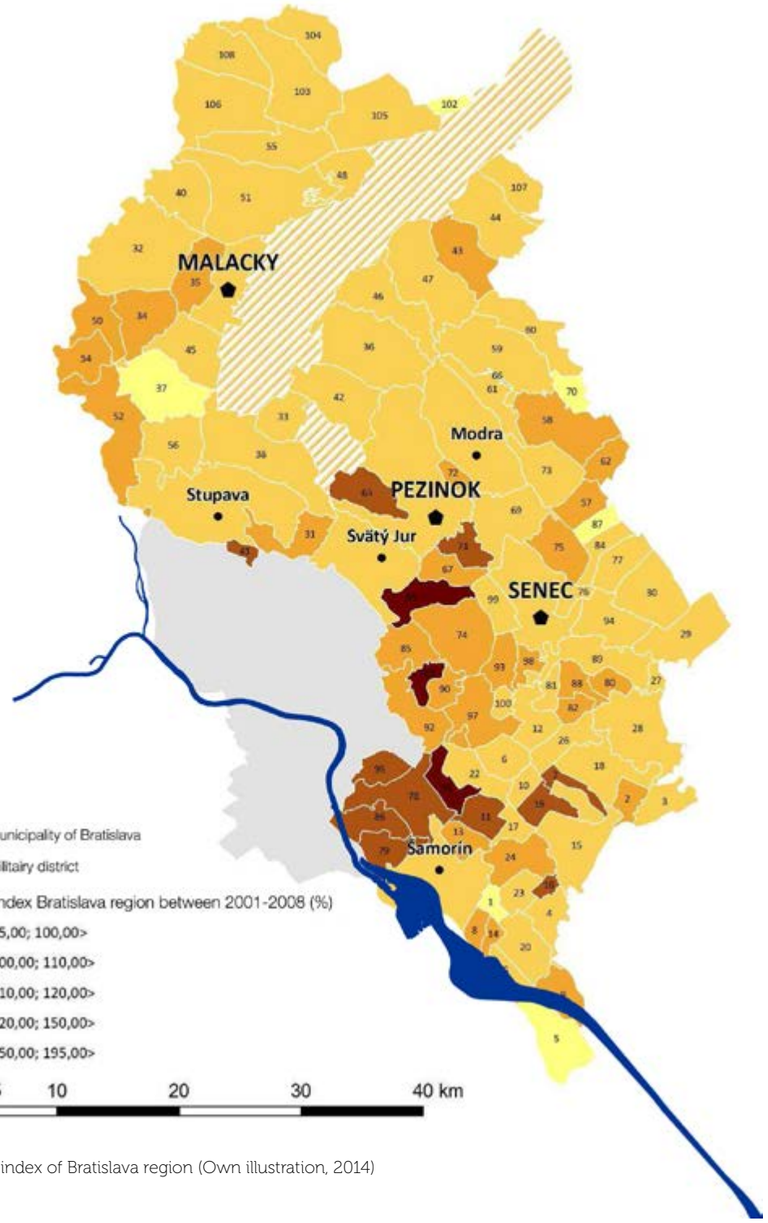
3.3 Decreasing flood forests

Directly linked to the normalization of the Danube is the loss of alluvial forests. The original river landscape of the Danube in the Bratislava region was a meandering river with a wide floodplain. These floodplains would be covered with large flood forests, wetlands, gravel and sand deposits and oxbow lakes creating a diverse ecological landscape.



Source: wwf.org (2013)

Remaining flood forests (Own illustration, 2014)



Growth-index of Bratislava region (Own illustration, 2014)

3.4 Urban sprawl

The normalization of the Danube made it possible for people to start inhabiting the former floodplains of the Danube. But living in these low laying areas comes with a risk, because of the Gabcikovo dam the Danube changed from a river flowing through the landscape into a river laying on top of the landscape. The inland delta functions now largely as a polder, with a high risk potential for flooding.

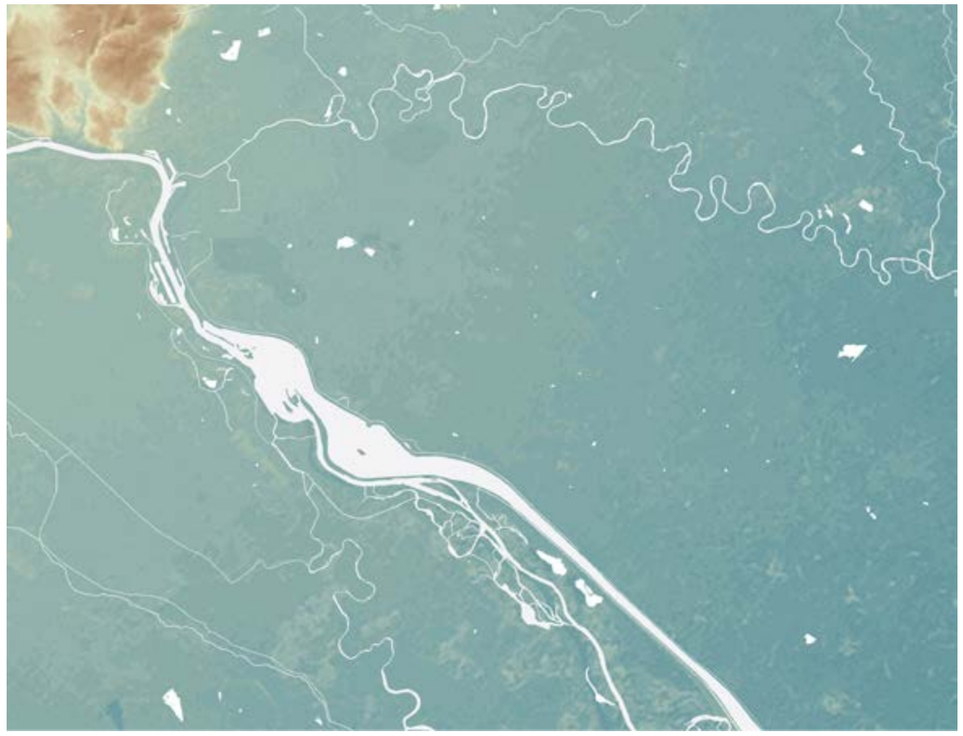
Geomorphological map; old river/creek meanders and sandy ridges (Own illustration, 2014)

Remaining flood forests (Own illustration, 2014)

4. Analysis

4.1 Natural landscape

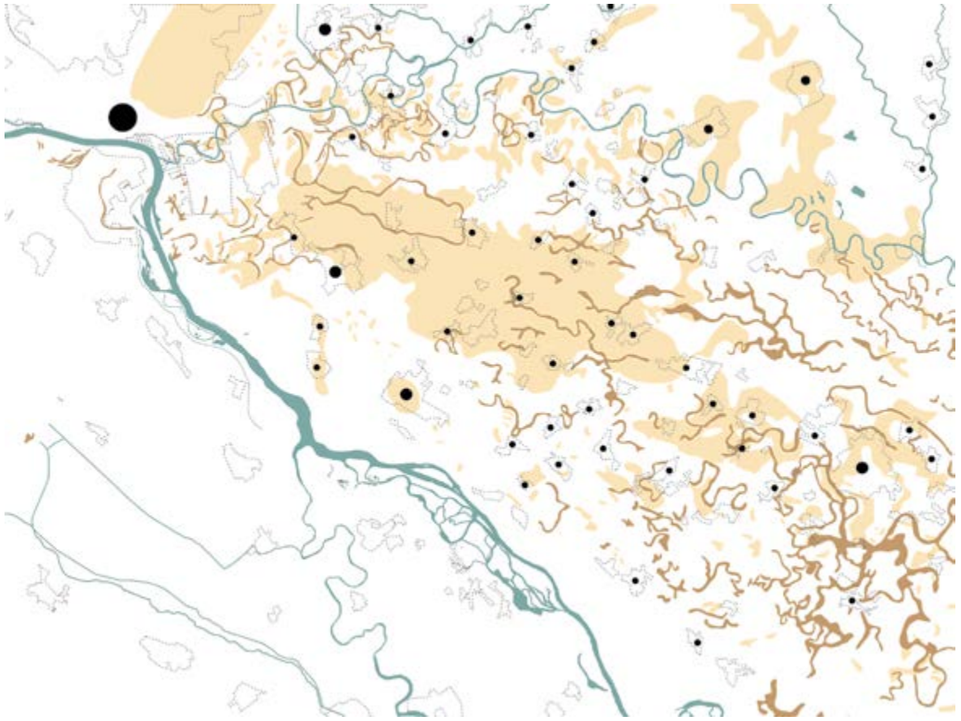
The inland delta, where the main focus of my project lies, used to be a dynamic river landscape, with the Danube as a driving force behind the constantly changing landscape. The Danube would flow from the Black Forest through Germany and Austria and would enter Slovakia through the Devin Gate, a narrow gap in the Carpathian Mountains. Here it would flow onto the Little Hungarian Plain, where it splits into three and would slow down and meander freely. These old meanders are still visible in the geomorphological layers. This former dynamic river landscape was constrained when in 1960 the Gabcikovo hydroelectric dam was constructed. Changing the river flowing through the landscape into a channel on top of it. This caused the natural habitat, the flood forest to disappear.



Elevation map (Own illustration, 2014)

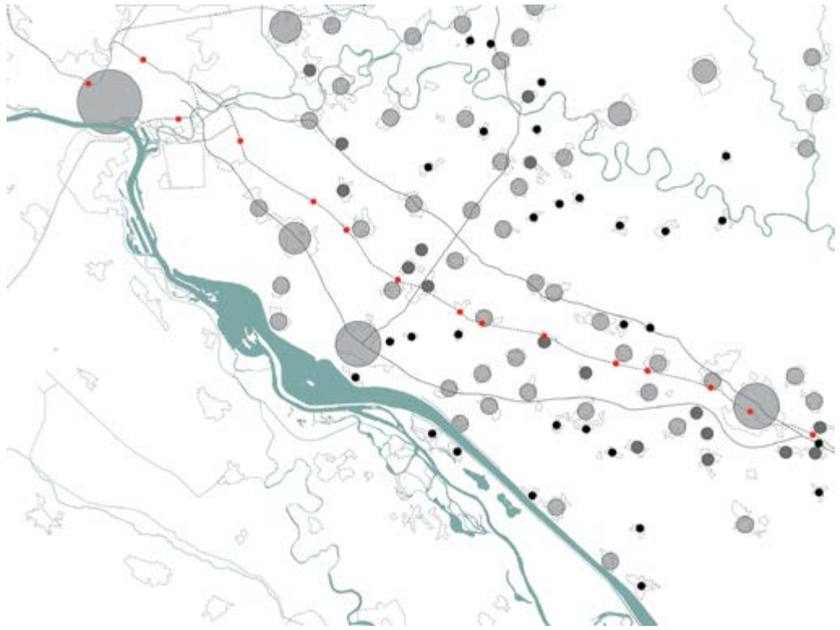
4.2 Urban development

The urban development of the inland delta has three distinct moments in time that shaped the urban structure like we see it today. The first known settlements came around 1200 on higher, and thus dryer areas and along the various creeks in the fertile inland delta. People avoided building right along the main flow of the Danube, where it was too risky to build next to. It was possible for Bratislava because the Carpathian Mountains created a high position right beside the Danube. Around 1900 the main roads and railway between Bratislava and Dunajska Streda were the most dominant factor in the urbanization of the inland delta. In 1960, when the Gabcikovo electro dam was constructed together with the canalization of the Danube new settlements were build right along the river. The most dominant growth can be seen in Bratislava itself and the cities lying on the different infrastructure crossroads.



1500 - New settlements on sandy ridges and along creeks (Own illustration, 2014)

1900 - Growth alon g main roads and railway (Own illustration, 2014)



2010 - Urbanization along major infrastructure and next to the canalized Danube (Own illustration, 2014)

5. Design goal

5.1 Research question

How can we transform a former dynamic river delta that now functions as a polder into an adaptive, flood resistant landscape on the basis of a 'natural' framework with opportunities for both ecology and economical development?

By defining a clear research question you are able to better structure your project and determine whether your final design has succeeded in your goal. This question is open for change throughout the design process and has so throughout the graduation project.

5.2 Design statement

Designing a spatial framework that will be used as a dynamic flood protection system by reintroducing a near-natural river dynamics in the form of a new river system through the inland delta, linking low dynamic processes like flood protection, ecology and recharging groundwater to build a robust framework in which the high dynamic functions can transform and grow without interfering with the long-term goal, an adaptable environment for both men and nature and in the process link the city of Bratislava to its surrounding landscape.

Plan Ooievaar (H+N+S, 1986)

6. Theoretical Basis

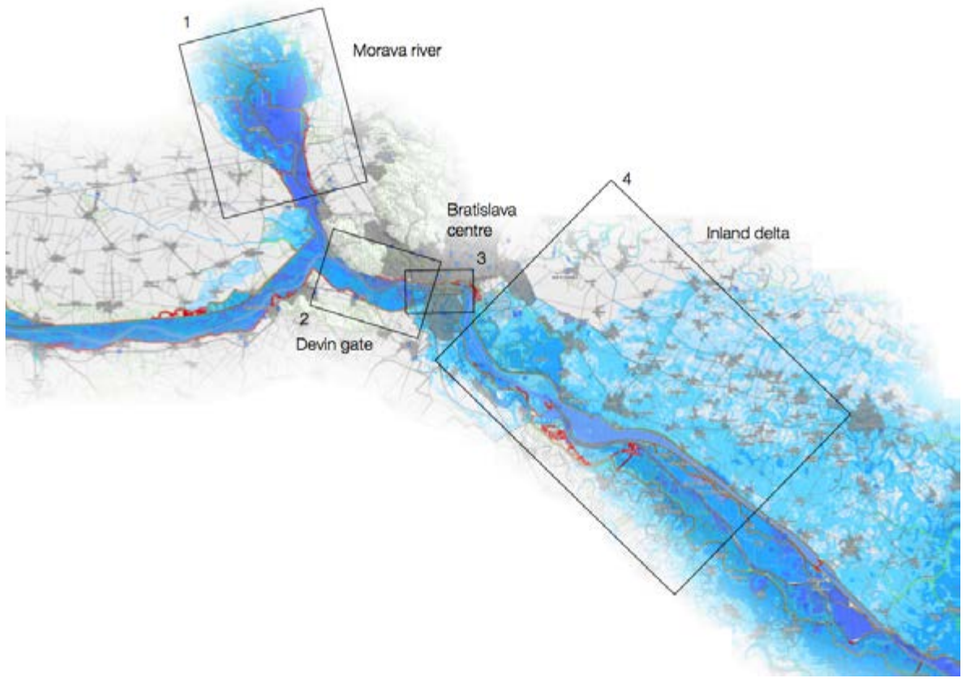
As a landscape architect you derive many of your ideas and decisions from a spatial theory. You build on the work of others, in my case mainly 'Plan Ooievaar'. It might have to do with the fact that I have a BSc in Civil Engineering before I made the transition to Urban Design and now Landscape Architecture. Room for the River was seen as the ultimate answer for the problems that would occur with the changing climate, though it was more from a hydro engineering point-of-view than a landscape architect. The spatial and theoretical basis for Plan Ooievaar was a "casco", or framework concept.

The framework concept is based on the paradox of time and uncertainty. Change and uncertainty are a given in both natural and cultural systems. It is no different in landscape, change is inevitable and there is always a degree of uncertainty. This is the paradox of time in landscape architecture and planning. Often you design with a certain image in mind but there is a long process proceeding before this is achieved. With large-scale projects it is not about only designing towards a certain final image but more designing the 'journey' your project follows.
Some key ecological processes, like development of flood forests or groundwater recharge require a certain level of stability to function within acceptable limits. These are the "low dynamic" functions. In the case of groundwater recharge, a degree of stability is necessary in terms of vegetative cover, soil stability, and nutrient inputs to maintain a renewable supply of clean groundwater. Other processes in the landscape, driven by social and economic forces, are more uncertain and "high dynamic" like land-use change, and require flexibility. The framework provides nature a long-term stability and allows more flexibility for land use change in the other areas. This is the framework's trade-off.[25] A "casco-landscape" is both a spatial and conceptual framework for landscape planning.[26]

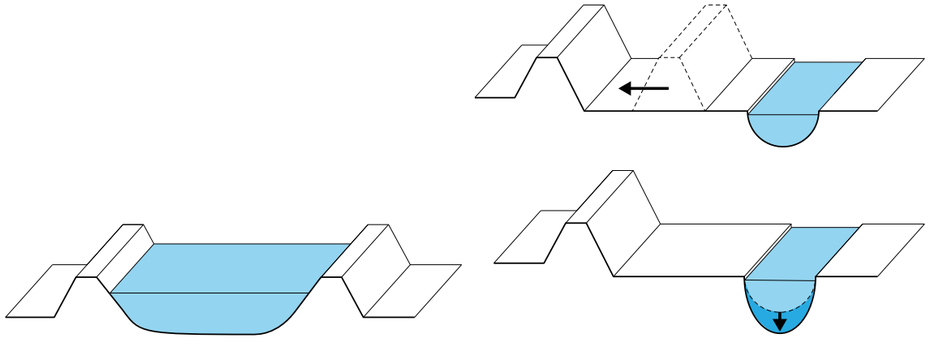
The framework concept promotes a spatially integrated network of areas, managed for "low dynamic" functions and uses, based primarily on abiotic actors. It is spatially defined by the existing hydrologic landscape structure, in which discrete geohydrological units can be identified.[27] In this case of the Floodscape project the low dynamic framework is mainly linked to the old river and creek flows, which are still visible in the geomorphological layer. Within this network structure, which is reserved for "low dynamic" functions, are opportunities for "high dynamic" functions and uses such as urban development, agriculture and economical functions.

In 1985 the 'Plan Ooievaar' was the winning entry of the 'Eo Wijers competition', proposing a new structure and water management strategy for the Dutch river landscape. It was one of the first projects in which the casco-concept was used in practice. The casco-concept can be seen as a designed landscape framework, existing of a network of areas, in which optimal conditions are offered for the development of high-dynamic land use forms.[28] The use of this concept in the river floodplains of the Dutch rivers has led to the formation of a coherent framework of self-regulating natural processes, which also made exceptional forms of recreation possible within these floodplains. The importance of 'Plan Ooievaar' and the casco-concept is illustrated by Hofland and Meeuwsen:
"The casco-concept and the 'Plan Ooievaar' were milestones in the involvement of landscape architects in the integral design of water and land on the regional scale".[29]

25 Ahern and Kerkstra 1994
26 Hamhuis et al. 1992
27 Kerkstra and Vrijlandt 1990, Buuren van and Kerkstra 1993
28 van Buuren, 1997
29 Hofland & Meeuwsen, 2011, p. 19



Key locations in solving the flood risk in the Bratislava region(Own illustration, 2013)



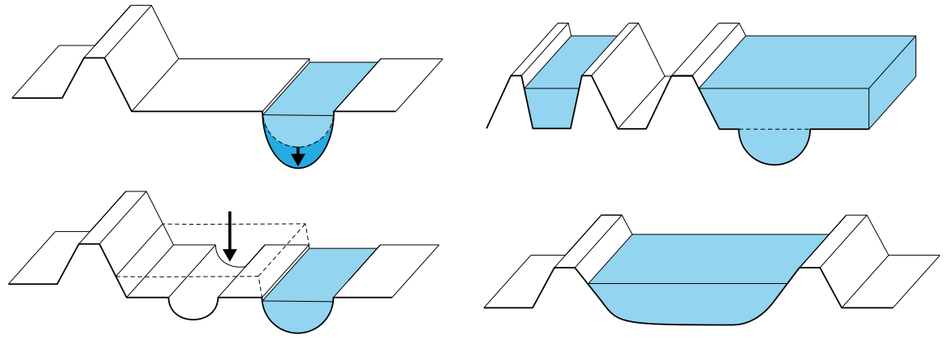
Morava nature area (Panaramio.com, 2013)

Floodplain Danube (Panaramio.com, 2013)

7. Design

7.1 Framing in a larger scale

The solution for the large-scale flood risks the Bratislava region faces and the impact it has on the Danube further downstream is not a matter of finding a solution on one specific location. It is a carefully weighed combination of interventions up- and downstream of Bratislava. Having been taught in the Dutch tradition of Civil Engineering I use the Room for the River toolbox.
In the case of Bratislava, there are four key locations with each their own solution. The Morava River that connects to the Danube from the Czech Republic has a large low-lying area that would be ideal as a natural retention area. Both ecology and flood prevention would be served by this intervention. Just upstream of Bratislava, the Danube flows through the Devin gate, a narrow gap in the Carpathian Mountains. Increasing the possible discharge is possible by lowering the floodplains and if necessary moving the Southern dike further inland. In the city of Bratislava, with its constructed shores a solution can be found in dredging the riverbed. Also removing obstacles will increase the possible discharge. The forth location is the inland delta, the solution here will be further elaborated in my design.



Room for the river toolbox (Own illustration, 2013)

Danube through Bratislava (Flickr.com, 2014)

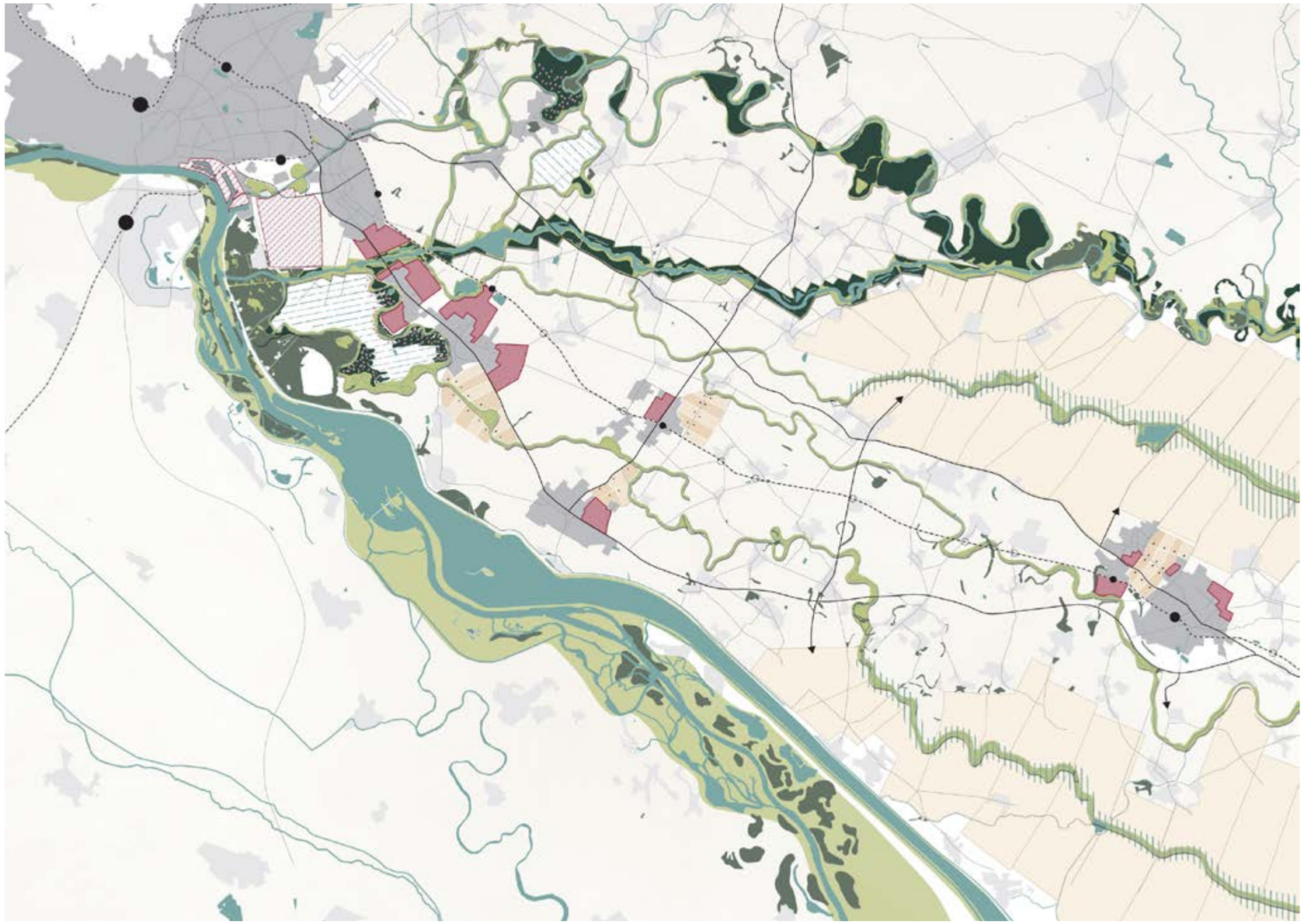
Inland delta (Google Maps, 2014)

7.2 Concept casco system

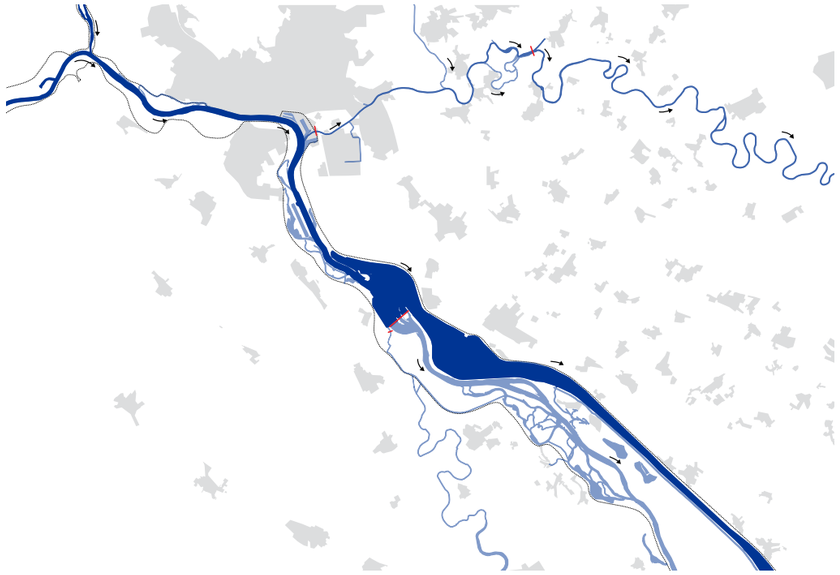
As mentioned before, the design is an elaboration on the casco, or framework system. The framework will be build up out of low dynamic functions; the water system dealing with the flood prevention and drought issues and the ecological connection of flood forests. These functions have a large time frame, within this framework there is space for high dynamic functions, urban development and transformation, agriculture and infrastructure are among those. The framework also gives opportunities for a new recreational landscape to develop.

7.3 Regional structure

The regional structure shows the potentials and possibilities of the new casco landscape. It deals with the issues that are relevant now, for instance the urban sprawl in the inland delta. Furthermore it links to the trends that are already happening.



Regional plan (Own illustration, 2014)



Current water system(Own illustration, 2014)

Q_{1000} = 13.000 m^3/s

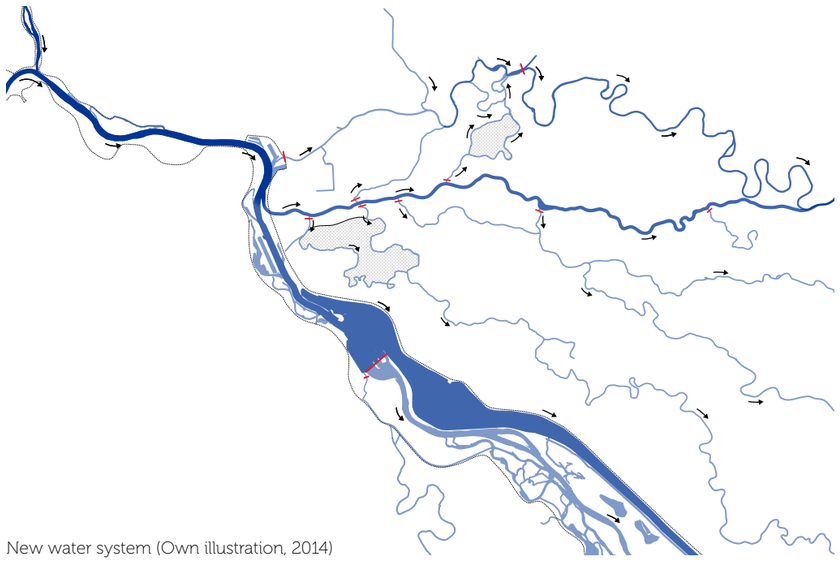
Danube discharge with a 1/1000 likelyhood to occur in Bratislava.

Q_{1000} = 13.500 m^3/s

Completion of flood protection wall in Bratislava based the revized Q1000 discharge.

Q_{1000} = 14.500 m^3/s

Q_{1000} = 15.525 m^3/s



New water system (Own illustration, 2014)

8. Water system

8.1 Form

The new watersystem will consist out of one main river through the landscape, connecting the Danube with the Little Danube running parallel. From this main river there will spring different creeks that flow freely through the delta. The route of this watersystem is directly linked to the old meanders which are still visible in the geomorphological layer. These old meanders are up till this date the low laying areas in the landscape. The course of the main river is however altered to accommodate the existing infrastructure and parcel lines, making it easier to realize.

8.2 Capacity

The changing climate will have an impact on the discharge of the Danube. It is expected that the maximum discharge will increase significantly over the next decade. At this point there is no comprehensive projection available for the Danube region, so I turn to the research of the rivers Rhine and Maas, done in 2001 and re-evaluated in 2007 by Rijkswaterstaat, a branch of the Dutch Ministry of Infrastructure and the Environment to make a rough calculation on the possible impact of the rise in average temperature. Rijkswaterstaat researched the possible change in discharge with the help of climate scenarios. The time frame they choose was 2050 and 2100. In all scenarios the extremes became more extreme, the maximum discharge increased and became more frequent and moments of drought would occur longer and more often. The different models showed an extra 5% peak discharge (Q1000) for every degree in temperature rise. This will be the basis for the calculation on the Danube watershed.
The projected annual near-surface temperature is somewhat different for the Danube basin. Where the annual temperature in the Rhine basin will increase with 1ºC until 2050 and 2-2,5ºC in 2100, the Upper Danube basin will see a projected increase of respectively 1,5ºC and 2,5-3ºC. This means an increase in extreme discharge waves of 7,5% in 2050 and 12,5-15% increase by 2100. Which results in the extreme discharges seen below.

With the existing water system dimensioned to a current maximum discharge of 13.500 m3/s, the main river through the delta needs only to handle the excess in discharge. Which will be 1000 m3/s by 2050 and 2025 m3/s by 2100. With a capacity of 83,2 M m3 in the first and 99,5 M m3 in the second phase the system has enough storage capacity to prevent high water waves traveling further downstream. Appendix 1a/b/c have a further elaboration on the calculations basis and data.

Creek after construction (Own illustration, 2014)

Creek growth flood forest (Own illustration, 2014)

Creek flooded (Own illustration, 2014)

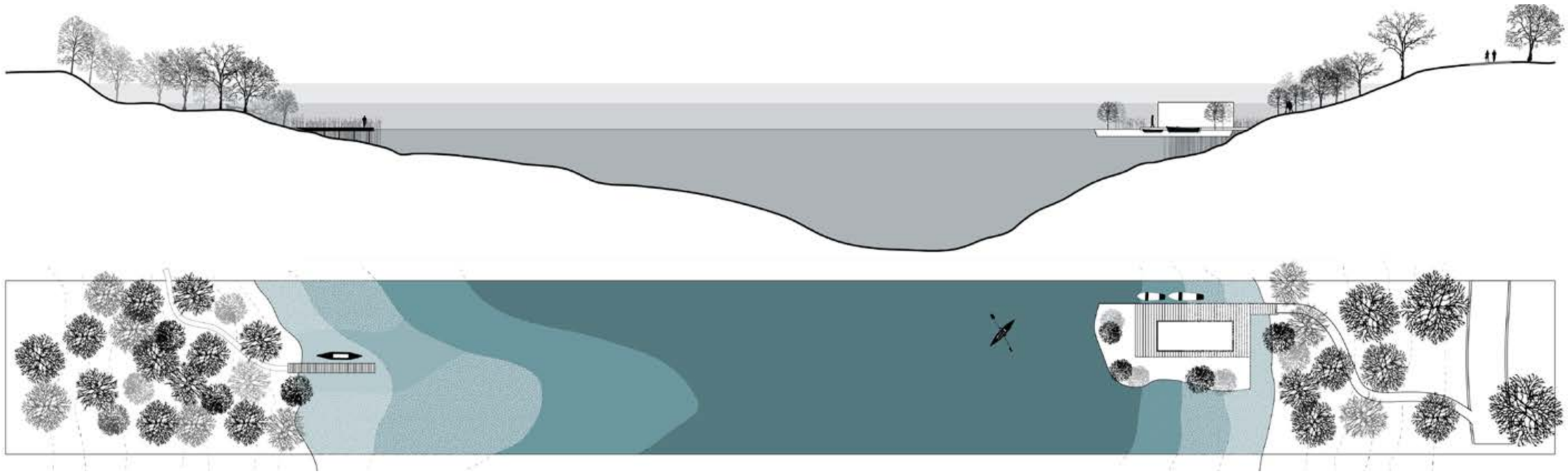
8.3 Construction

Constructing a new river across a 30 km stretch is a costly undertaking; almost the entire course needs to be excavated. But by strategically giving out permits for excavating gravel and sand along the new course of the river parts could be completed without needing a large investment. The funds gained from the permits could be used to further complete the river system.

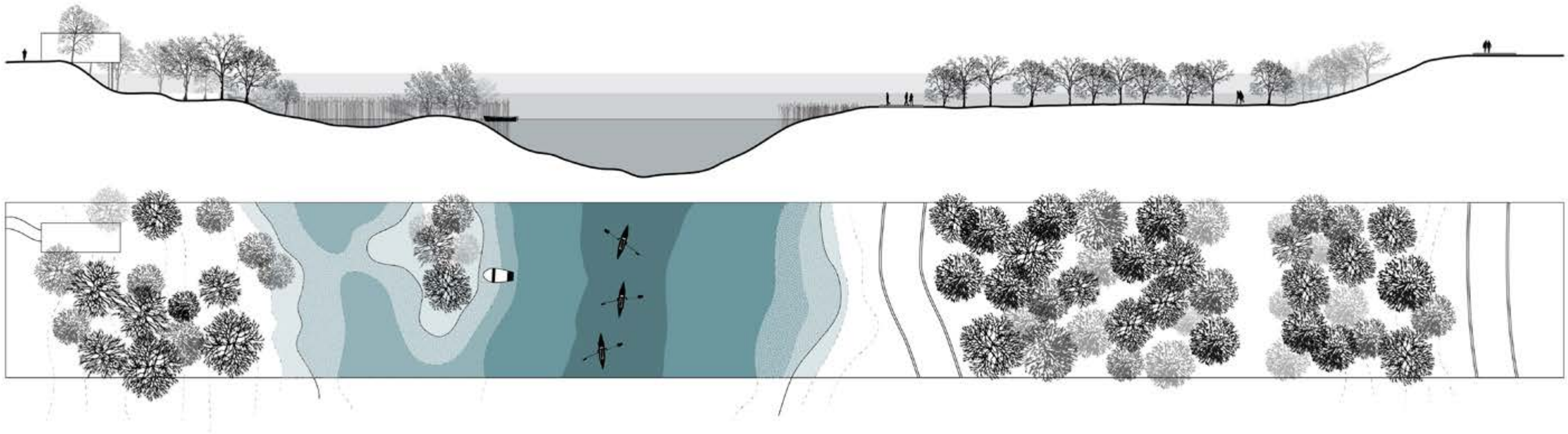
8.4 Adaptability

The project is designed in such a way that it is possible to further increase the rivers capacity by extending the floodplains. This second phase of the river should be enforced using ground use regulations. Grey poplars will be used to mark the future dike.

Impression building landscape (Own illustration, 2014)



Section main river/lake (Own illustration, 2014)



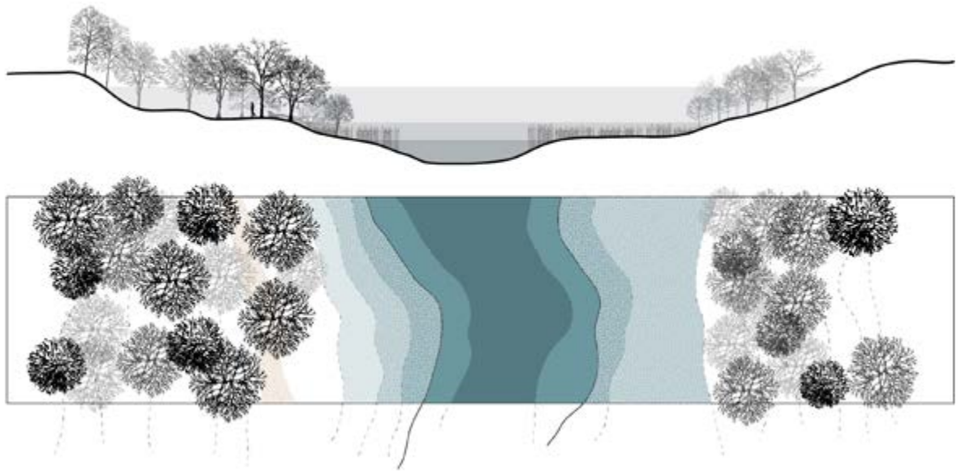
Section main river (Own illustration, 2014)

9. Low dynamic system

9.1 Ecology

Dynamic ecology in an inland delta system

One of the major goals of the design is to bring dynamics back into the inland delta, also known as the Danubian Plain. Before man-made interventions changed the delta from a dynamic water landscape into a static polder the area was capable of retaining much more water than it can now. The element that will be the driving force behind the new dynamic water landscape will be the water from the Danube that flows into the different river arms and streams that will change the ecological and spatial conditions. The ecology in the area will be focused on these ever changing conditions. This system with periodic floods is similar to how the Danube used to function in the delta before the river was canalized using dams and dikes. Alluvial forest used to be the main landscape type along the Danube and they will be on of the main habitats along the new main river. It will make the connection with the ones along the Danube. These alluvial forests are among the most endangered types of habitats in Europe but they are of vital importance and have a high amount of biodiversity. But because of the construction of dams in the Danube for hydroelectric power plants and navigational ability in the last decades many alluvial forests were lost.[30]



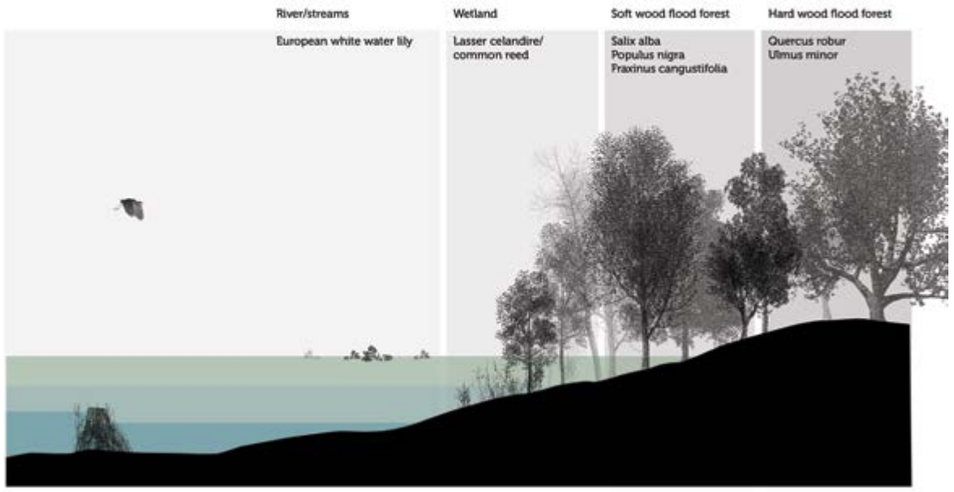
Section creek (Own illustration, 2014)

30 fig. X

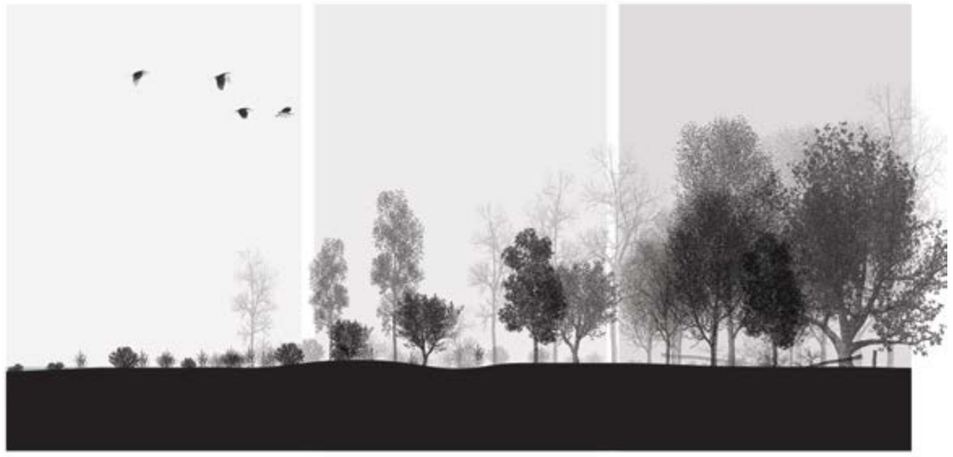
An example of a landscape that still has these river dynamics and alluvial forests is the Donau-Auen National Park along the Danube between Vienna and Bratislava and the Dunajské luhy Protected Landscape Area just downstream of Bratislava on the Slovak-Hungarian border. The Donau-Auen National Park has a direct link with the Danube and floods whenever a high water level occurs. The ecological cycle is dominated by the moments when the Danube flows over the floodplain. High water levels are caused by "snow-melt from the mountains from late spring to mid-summer; high water levels caused by precipitation may occur throughout the year".[31]
The Dunajské luhy is somewhat different because the water level can be regulated through a system of weirs. It runs parallel to the controlled flow of the Danube after the construction of the Gabčíkovo-Nagymaros project in the 1960's where two dams were constructed for hydro power plants. When dealing with different water levels and flooded plains throughout the year the ecology will need to be able to adapt to these changes. Take for instance the influence high water level has on trees, not all tree species are suitable to withstand conditions where it is partially submerged a number of days per year. On these floodplains hardwood broad-leaved trees like the oak (Quercus) and to a lower degree also the ash (Fraxinus) will not be able to survive and start to rot and slowly disappear. But they will be replaced by other, more suitable trees like white willows (Salix alba), crack willow (Salix Fragilis) and poplars (Populus Nigra, Populus Alba, Populus x Canescens)[32].
You could remove the trees that cannot survive in these conditions but the dying trees will create interesting conditions for numerous plants, insects and other animals. Some dead trees will be swept away during high water levels and dropped further downstream where it can function as a hiding place for fish or other water fauna. The design will create a network of streams throughout the inland delta. This framework is build out of one main spine, the river arm through the inland delta, and several rib-cages originating from this river arm in the form of different smaller streams flowing from the main river arm. The main river arm and the smaller streams will function on different levels, the river arm has high hydrological dynamics but it is also has a recreational program so it needs to be designed robustly to withstand the pressure from both human activities and. It has to be able to deal with occasional flooding, during extreme high water levels in the Danube the river arm together with its lakes will function as a retention watershed. During these periods the water will flow over the floodplains making it one of the major events in the ecological calendar.
The smaller streams won't be highly programmed like the main river and are of a different, smaller order. They will flow meandering through a floodplain that varies in whit. The streams will be able to freely meander where possible creating a constant dynamic situation where erosion en deposition play a big role[33]. These stream will connect larger patches of wetlands with each other. These patches are placed with a certain regularity along the stream so they can create a habitat for different animals. The placement of these patches are directly linked to certain key species.

31 Nationalpark Donau-Auen GmbH, 2011
32 Kocinger, 2002
33 fig.X

New ecological framework (Own illustration, 2014)



Section flood forest(Own illustration, 2014)

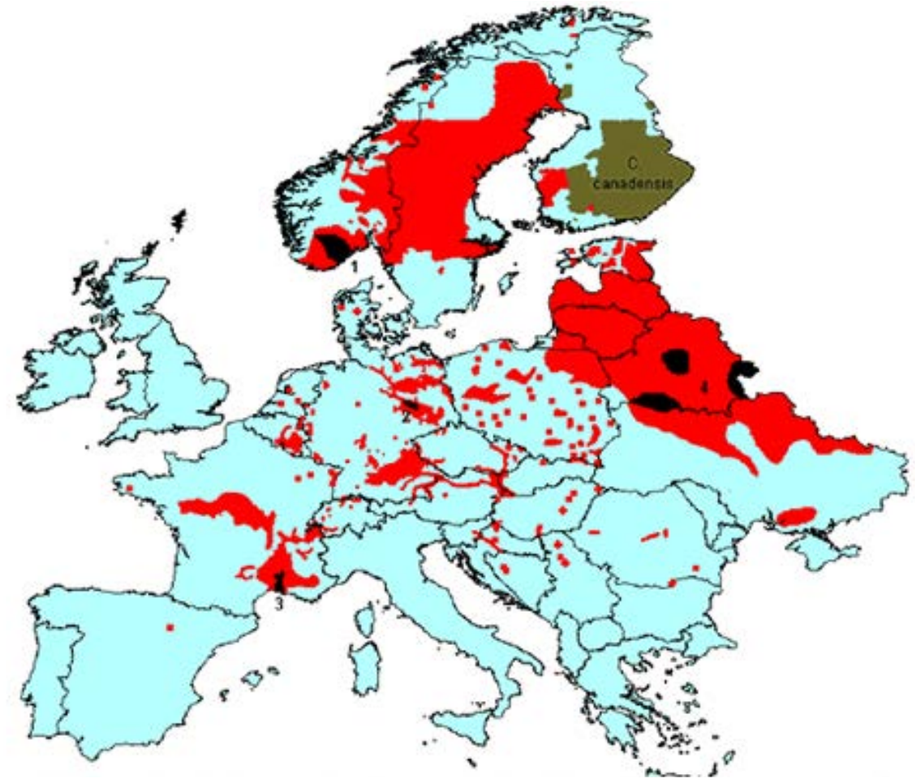


Succession forest(Own illustration, 2014)

Impression flood forest along creek (Own illustration, 2014)

Focus on species

When you talk about ecological connectivity, you don't only talk about making a connection from A to B. It is dependent on the type of species you are dealing with. So it cannot be addressed solely on the basis of a generic landscape mosaic, you have to make it specific. One approach is to select different target species that will be used as the basis for the design of ecological corridors between protected areas. Ecological connectivity depends on landscape structure as well as on the mobility and ecological requirements of the species in question.[34] Because connectivity occurs on different scale levels, I decided to focus on two species that each requires a different type of habitat in both scale and form. In this project I have chosen for the European beaver and the European turtle. The beaver for its capabilities of altering the landscape through dams or weirs[35] and the turtle for the diverse habitat it needs creating an interesting mix for a wide range of other animals.



Beavers throughout Europe (www.welshbeaverproject.org, 2013)

34 Bunn, Urban, & Keitt, 2000, p. 266
35 fig.X

Beaver dam (google.com, 2014)

Beaver

"For millions of years, beavers[36] *has been an integral part of the Danube basin fauna."*[37] In the 19th century the beaver (Castor fiber) was completely exterminated in the Danube basin, it wasn't until 1966 when the beaver was reintroduced. Nowadays the beaver is gaining ground throughout Europe with the larger populations in Scandinavia, Russia and the Baltic States.[38] But along the Danube there are many stretches where it is impossible for the beaver to settle due to the constructed riverbeds. The beaver is capable of adjusting the landscape to its own needs, similar to men but with a large river like the Danube it is very hard to control the water level, which they need to be able to do for a good habitat.[39] Depended on the size of stream and the surrounding territory a family of beavers will need a stretch between 1 and 5 kilometres to maintain itself. The beaver feeds itself with fresh plants and during wintertime, when fresh plants are scarce they eat twigs from trees. To get to the twigs the often chop trees down with their sharp teeth, unlike popular believe they let the wind give the final push to bring down the tree. The beaver will create diversity in dry and wet places, its need slow moving or stagnant water with a certain depth to maintain itself. The dams the beaver builds will create habitats where many other species will thrive; ponds and wet areas upstream and dryer places downstream of the dam. In doing so it gives the possibility for the species like European pond turtle to settle in the same area. But also otters, ducks, fish, reptiles and amphibians

36 fig.X
37 Valachovič, 2009, p. 2
38 fig.6.X
39 Valachovič, 2009, p. 11

European ond turtle (google.com, 2014)

European beaver (google.com, 2014)

European pond turtle

The European pond turtle (Emys orbicularis)[40] is the only native turtle in Europe and is considered an umbrella specie for nature conservation.[41] It needs a very specific combination of habitats, stagnant water with lush vegetation and sandy areas to lay their eggs. The European pond turtle lays her eggs not directly next to the water but on average 350 meters away. This needs to be taken into account in the design. Another important characteristic of the habitat of the European pond turtle is enough open space for basking sites, open areas where the turtle can warm itself in the sun, mainly in early spring. It's a matter of maintenance whether there will be enough clearance, this could be done manually or regular grazing by sheep e.g.

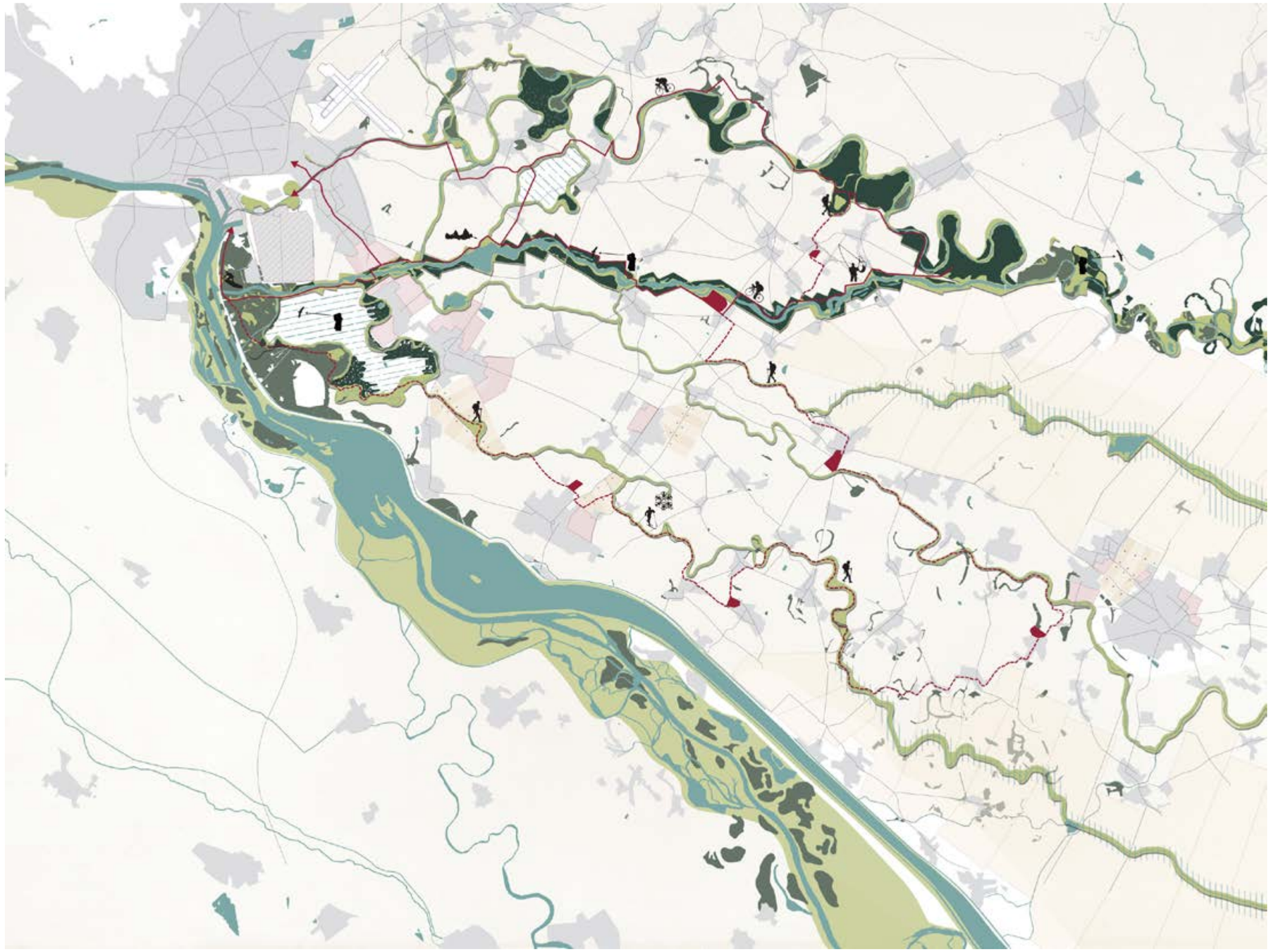
40 fig.X
41 Cadi, Nemoz, Thienpont, & Joly, 2004, p. 89

9.2 Recreation

The new spatial framework and the landscape it creates gives many opportunities to recreation. Be it canoeing through the system of river, lakes and creeks or going for a long bike ride along the major river. But maybe the most interesting opportunity and the favourite pastime for many Slovaks is going on a hike. Often people travel to the Carpathian Mountains during the weekend and go on long hikes through the landscape, where they stay in lodges or B&B's. The new landscape gives the people from Bratislava an opportunity to go on a hike through the inland delta. These hike paths could follow the spatial framework and be linked to different estates often with a public park that lay throughout the region. A few of them already have a function, some private, some public but many are unused and could be renovated into B&B's, a tourist information centrum with restaurant or other functions to support the recreation use of the landscape.

Legenda

- bestaande stad/dorp
- potentie uitbreiding stad/dorp
- transformatie industriegebied
- nieuw woonvormen
- water
- wetlands
- waterzuiveringsgebied
- intensieve landbouw
- niche/multifunctionele landbouw
- hoofd infra
- secundaire infra
- spoorlijn & station

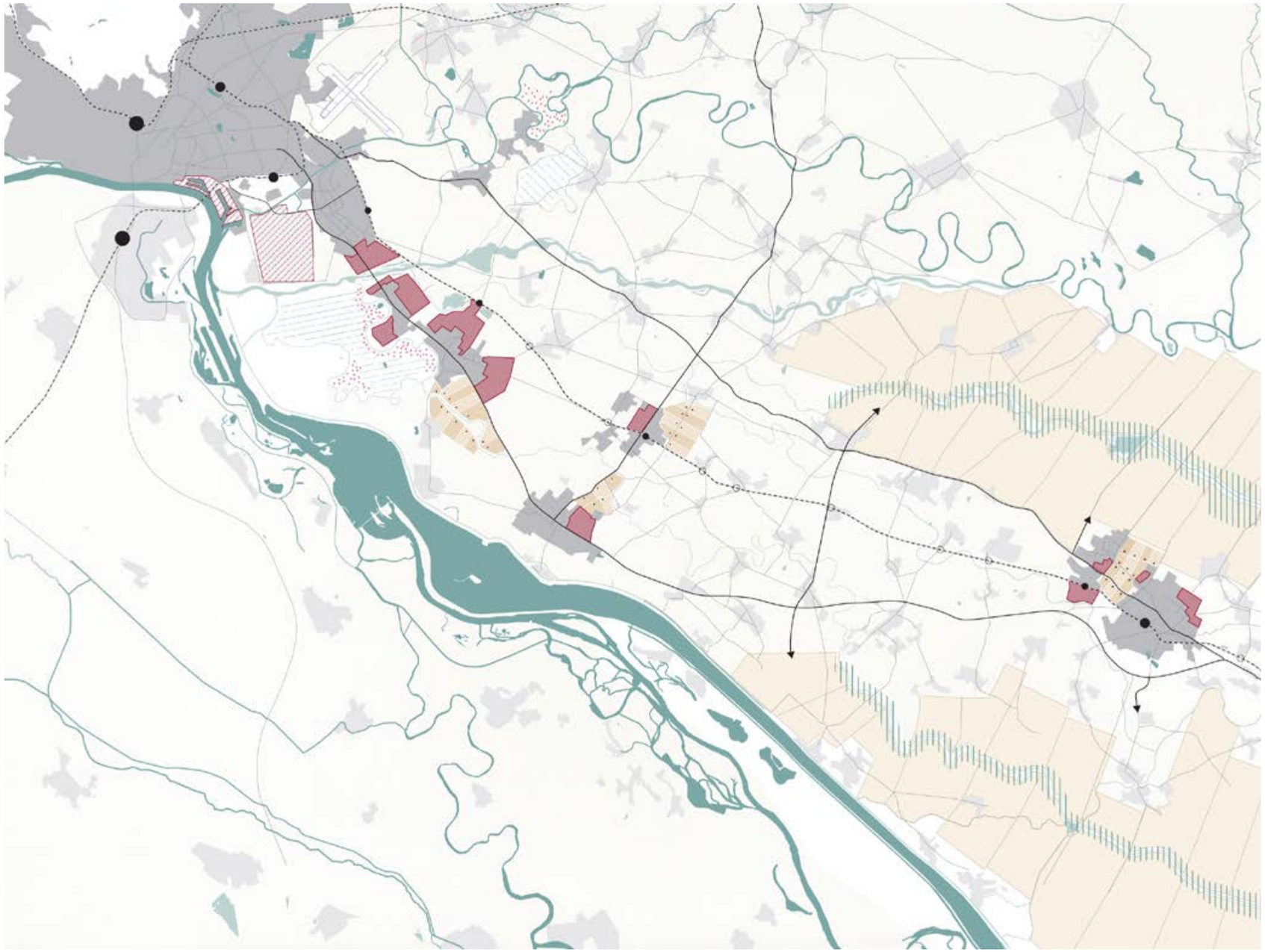


Recreational landscape (Own illustration, 2014)

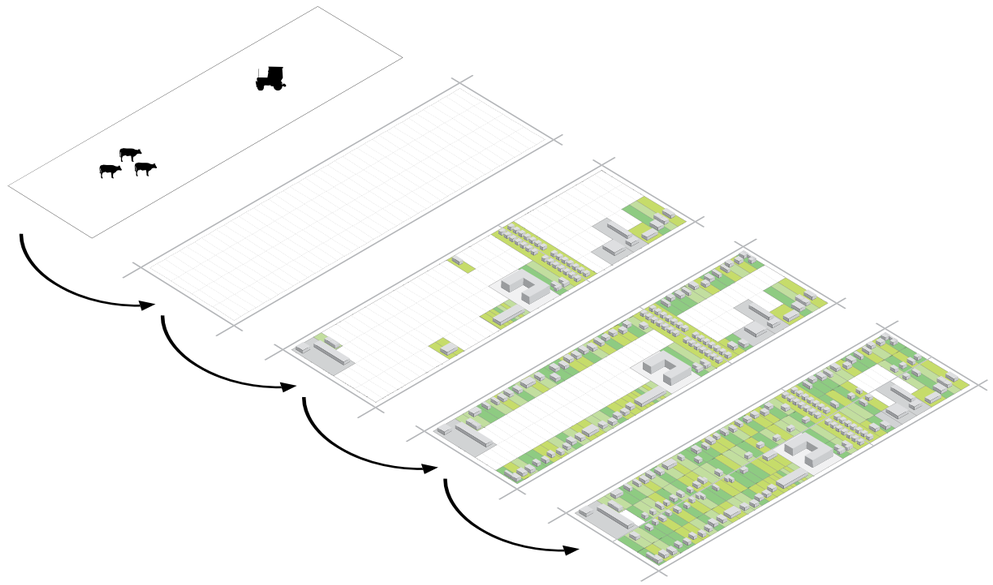
10.
High dynamic system

10.1 Urban development

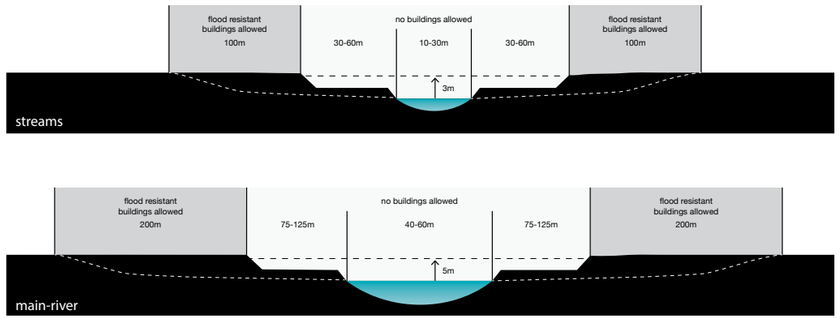
Because of the high demand in single-family housing in Bratislava and the current pressure on this segment of the housing market in the villages around Bratislava we could see some major growth in the direct vicinity of the capitol. By creating the right conditions the villages Rovinka and Dunajska Luzna could function as a new neighbourhood of Bratislava. Besides this, the biggest growth can be expected in the cities and villages who already have a high facilities level and a good connection with Bratislava by either car or train. The existing railway could be upgraded so the train could become a good alternative for the car. With the transformation of the landscape from a polder to a more dynamic river landscape new opportunities arise for unique living environments. In the retention area just West of the new Bratislava neighbourhood there would be an opportunity for specially adapted houses in a unique landscape. An advantage of this location is the close proximity of facilities in Bratislava. Living in nature but with all the facilities you need. This development could also contribute in the financial compensation of the farmers.
In time, the Slovnaft refinery and the harbour could be transformed into new economical activities.



Urban and agricultural development (Own illustration, 2014)



Model for growth from agriculture to urban (Own illustration, 2014)



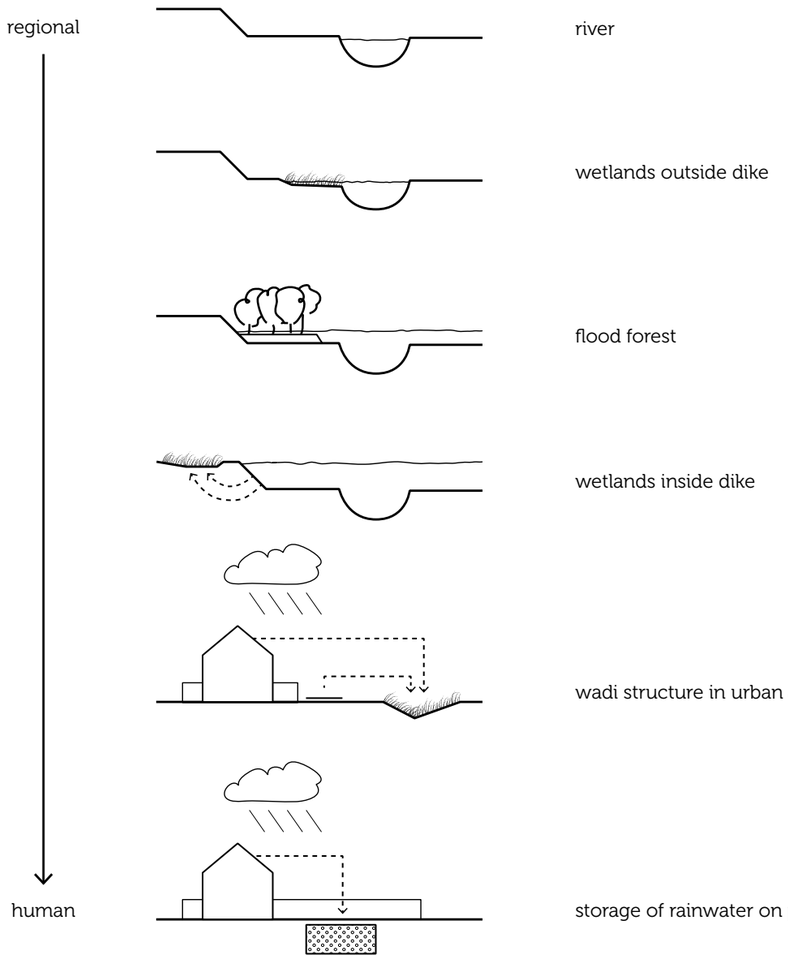
Restrictions on building along the river and creeks (Own illustration, 2014)

Detail of urban and agricultural development (Own illustration, 2014)

10.2 Connection Bratislava and the river

Water as structural elements

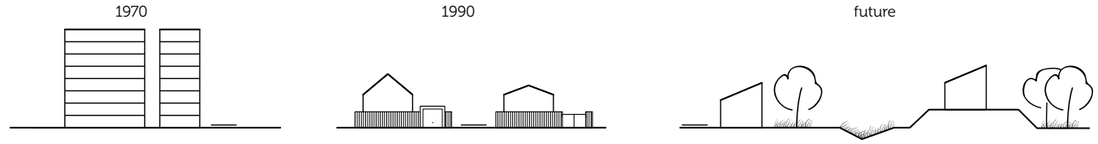
Illustrative for my project is the way water is used as a structural element throughout my entire project, from the big scale of the river on a European level all the way to the way we could deal with rain- and grey water on the individual plots. By using a gradient of water elements the design gives hierarchy. The connection between Bratislava and the new river could be seen as an illustration of this system of frameworks giving quality to a site in all scenarios. Whether there is a high demand in new housing locations or the growth falls short, all scenarios should bring an improvement of the current situation.



H_2O gradient (Own illustration, 2014)

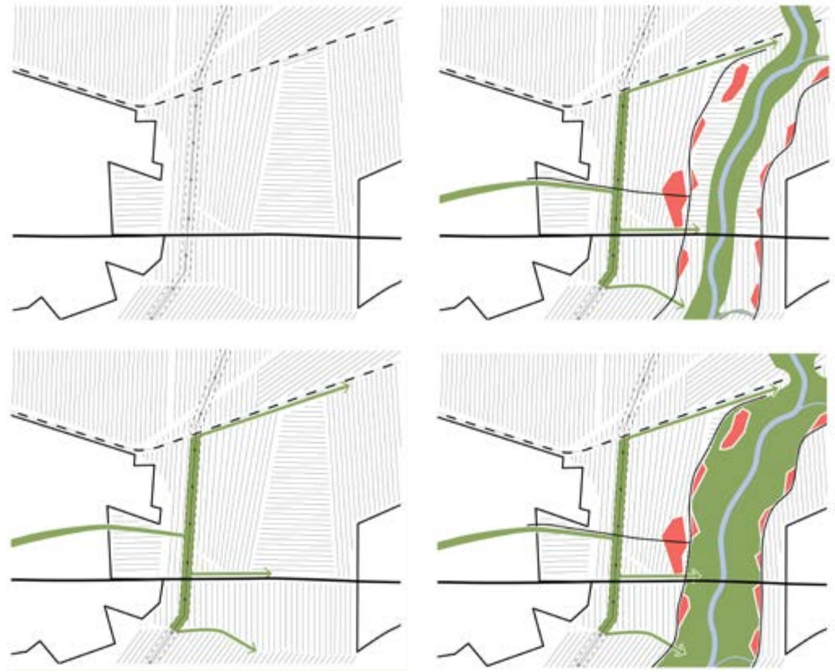
From city to floodscape

The connection between the city of Bratislava and the new river has been chosen as a means of illustrating the possibilities of the new landscape. The focus lies on connecting the city to the river in al scenarios and to come up with a design in the different phases of the river while also dealing with extreme rainfall and dry periods. These are having a negative effect on agriculture because of low ground water levels intensified by the ground well pumps of the Slovnaft refinery and the Gabcikovo project.



From Bratislava of the 70's - 90's to the future (Own illustration, 2014)

From the outskirts of Bratislava a connection is made by using a structure of bioswales, which is a system of water (in)filtration beds irrigating the agricultural fields with filtrated rain- and grey water from the nearby city. From the beginning of the project this will have a positive impact on the region. The bioswale is directly linked to the existing power lines giving structure to future developments, making a transition between the city of the 90's and the future city.



Phases of growth (Own illustration, 2014)

The existing structure from the city is continued and ends at a big mound build from the excavated soil from the new river. This functions as a first settlement along the river and it is a clear entity in the new landscape. The urban fabric on the west side of the bioswale is more structured like the connecting city where east of the bioswale the transition is being made towards a more living in the landscape typology.

Urban model for growth (Own illustration, 2014)

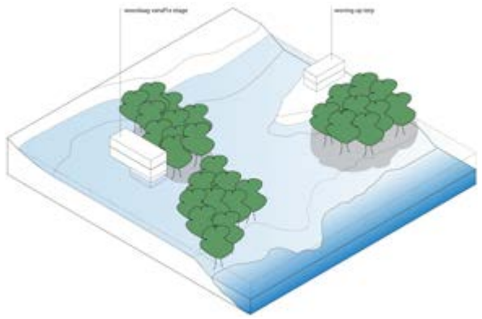
Like stated before, the river has a possibility of being expanded in the future when the capacity is insufficient in dealing with flood control. In this area building is allowed but only under certain regulations. In the first phase the future dike has the identity of a farmers' road, with clear plots along the road. These plots are shaped in geometrical forms where the dike itself flows through the landscape. The plots will become mounds in the flood plain when the river enters its second phase.

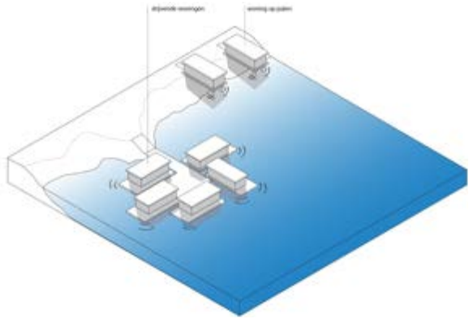
Phase 1 Plots along the future dike (Own illustration, 2014)

Phase 2 road transformed to dike (Own illustration, 2014)

New building types

The new casco landscape creates a more diversified living environment, where it used to be a mainly agricultural landscape it is now a landscape with rivers and creeks, flood forests and wetlands with patches of agricultural fields. These new landscapes create interesting conditions for new building types.





Studio Moffitt

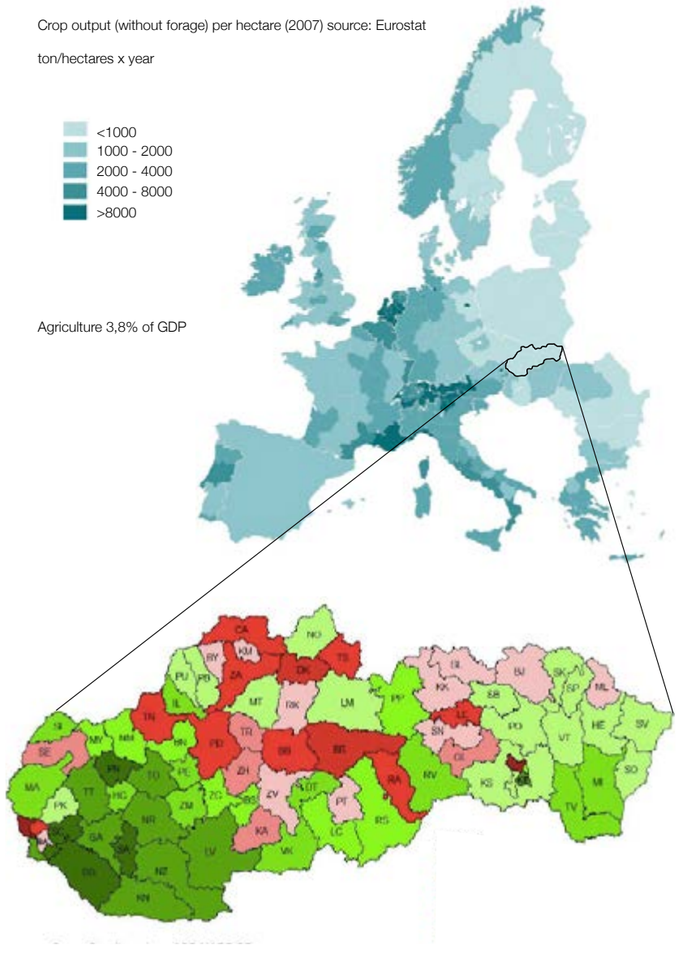
Artau Architectures

DELVA Landscape Architects

MacKay-Lyons Sweetapple Architects

10.3 Agriculture

Right now agriculture in Slovakia is still somewhat under developed and most surrounding countries are more productive. But because the inland delta is one of the most fertile lands in there is potential for intensifying agriculture and making it more profitable. This up scaling would focus mainly in the fertile clay soil parallel to the Danube. With the new water system in place to drain and clean the runoff water and a good connection to the main infrastructure we could see this area becoming more efficient. Along with this intensification of agriculture there would also be a potential for multifunctional and niche agriculture. You could imagine this being linked directly to the cities projected to grow with a close link to the consumer and recreational visitor/tourist.



Agricultural effeciency and fertility (Own illustration, 2014)

11. Reflection

The graduation plan Floodscape is part of the Landscape Architecture studio Flowscapes that focuses on landscape as a form of infrastructure.

"The studio explores infrastructure as a type of landscape and landscape as a type of infrastructure, and is focused on landscape architectonic design of transportation-, green- and water infrastructures. These landscape infrastructures are considered armatures for urban and rural development. With movement and flows at the core, these landscape infrastructures facilitate aesthetic, functional, social and ecological relationships between natural and human systems."[42]

The design focuses on implementing the lessons learned from the Room for the River project and taking it a step further to be able to deal with flood risks now and in the future. By creating an adaptive framework through the inland delta downstream of Bratislava a solution is being sought for the flood risk now and in the future.

The relationship between the theme of the studio and the subject/case study chosen within this framework

The choice for Bratislava was derived from both a personal experience I had with the city itself having visited it a few times earlier and a professional interest in the particular unique landscape of the Bratislava region. I felt it had a significant link with the theme of the studio being located in a country that is trying to catch up with Western Europe but still has a lot of uncertainties when it comes to dealing with changes in landscape, infrastructure, ecological developments and city expansion. By using the river Danube as a driving force behind the project it positions it firmly in the core of the studio's subject. The river is both landscape and infrastructure.

The relationship between research and design

In the beginning of the project the research mainly focused on natural processes that have the ability to create landscapes and what role a designer could have in using these processes to its advantage. How can we create a desired landscape by using the force of water for example? Later this developed to a more strategic and spatially tangible principle of the 'casco model' seen in plan Ooievaar[43], the initial plan that later was used to develop the 'Room for the River' project. This plan, the winner of the EO Wijers competition in 1986 was a new concept on the Dutch river landscape. The natural processes and ecological processes would be concentrated in the rivers and floodplains creating a strong spatial framework throughout the Dutch Delta.[44] It would create a flexible system that deals with controlling the higher discharge of both the river Rhine and Maas. The 'casco model' was a new vision on landscape planning, both spatially and in process. It would be build up by a 'low dynamic' framework; the long-term natural processes would be concentrated here. But inside the framework there would be the flexibility for 'high dynamic' processes

42 Nijhuis, Jauslin, & De Vries, 2013, p. 1
43 de Bruin et al., 1987
44 figure 1

and functions; like land-use change and urban expansion. These principles were the starting point of the final design.

The relationship between the methodical line of approach of the studio and the method chosen in this framework

My graduation project is focused on how the natural landscape, that is either present or lost due to human intervention can help in solving certain problems. The potential of the natural occurring landscape is often under appreciated while it can give designers clues for overcoming certain design problems and what this concept can mean on all scale levels. I think this method of approach is very much in sync with the method derived from the studio's core concept, where a multi-layered understanding of the landscape is being advocated.

Although my method of approach may sometimes come across as somewhat rudimentary, it is not. I carefully choose the direction I take my project in and ask myself the right questions. But it may seem like I jump over certain steps in dealing with a project that is both spatial and scientific. I don't always show or explain all the steps in my though process before arriving to a conclusion or design decision. While it is not my intention to skip right through the scientific and analytic basis for my project I often do this. It is my job as a graduate student to show not only that I am a skilled designer but also the underlying knowledge of my design. That is the biggest critic on my personal methodology in this graduation project.

The relationship between the project and the wider social context

Across the world people's environments are being threatened by the effects of climate change, and although we, and especially in Western countries are capable of fighting them in the same way we have been doing in the last 25 years there is a change in the way we think about possible solutions for these effects. The experience we gained by implementing the Dutch project "Room for the River" in the Dutch Delta shows us that the conventional solutions in river flood protection are no longer sufficient for the rapidly changing climate. This project deals with the uncertainty that comes with the changing climate and tries to address it in a manner that is not only a technical solution but also ads value to the overall development of a region.

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Appendix 1a

Calculation water system

In paragraph 7.4 Water system I discussed the impact of climate change on the extreme discharges of rivers, mainly caused by extreme precipitation. In this appendix I will elaborate more on the dimensioning of the water system as prove that the intervention has a hydrological foundation. The rise in average annual temperatures will result in a 5% (Appendix 1b) increase in discharge in the Rhine basin, and although the Danube is a different river it has some common characteristics. Especially the upper Danube. The rise in temperature will be slightly higher in the Danube region and thus I calculated with a higher increase for 2050 en 2100.

Danube Bratislava	Discharge (m3/s)	increase (%)
2010	13.500	
2050	14.513	7,5%
2100	15.525	15%

With the current flow of the river capable of dealing with 13.500 m^3/s it would result in a capacity deficiancy of around 1.000 m^3/s by 2050 and around 2.000 m^3/s by 2100. This surplus should be absorbed by the new water system. With the current capacity of the Little Danube at 1000 m^3/s there shouldn't be any problems for the year 2050.

	Discharge (m3/s)	Inlet from Danube (m3/s)	Capacity Little Danube (m3/s)	Balance (m3/s)
Q1000 2010	13.500	0	1000	0
Q1000 2050	14.513	1.013	1000	13
Q1000 2100	15.525	2.025	1000	1025

Especially if you would consider the retention capacity of the new water system which is 83,2 M m^3 in the first phase and could be increased to 99,5 M m^3.

	Lenght river (m)	Avg width river (m)	Surface (M m2)	Depth (m)	Capacity (M m3)	Total capacity (M m3)
Retention area I	-	-	16,2	2,0	32,4	
Retention area II	-	-	9,1	2,0	18,2	
River Phase I	32.600	200	6,52	5,0	32,6	83,2
River Phase II	32.600	300	9,78	5,0	48,9	99,5

But flood waves always have a curve, either steep or flat but it historically it has never happend that the Q_{1000} would continue longer than a day (Appendix 1c).

duration	Volume (M m3)				Balance	
(days)	Historic	2050 (+7,5%)	2100 (+15%)	Capacity 2010	2050	2100
T=2	1.766	1.898	2.031	2.333	434-	302-
T=5	4.079	4.385	4.691	5.832	1.447-	1.141-
T=10	7.004	7.529	8.055	11.664	4.135-	3.609-

Appendix 1b

Reference

De Wit, M., Buiteveld, H., Van Deursen, W. Klimaatverandering en de afvoer van Rijn en Maas Rijkswaterstaat RIZA WRR & Carthago Consultancy, Rotterdam Arnhem, Juni 2007, RIZA memo: WRR/2007-006

verandering van de maatgevende afvoer van de Rijn volgens G en G+ scenario zal ongeveer gelijk zijn aan de verandering in WB21 midden scenario en de verandering van de maatgevende afvoer van de Rijn volgens W en W+ scenario zal ongeveer gelijk zijn aan de verandering in WB21 hoog scenario. Voor de Maas levert het vergelijk in de winterafvoeren met KNMI06 en WB21 scenario's een ander beeld op: WB21 lage scenario komt ongeveer overeen met G, G+ en het WB21 midden scenario komt ongeveer overeen met W, W+. Doorredenerend zou je dan de volgende vuistregel kunnen gebruiken: de verandering van de maatgevende afvoer van de Maas volgens G en G+ scenario zal ongeveer gelijk zijn aan de verandering in WB21 lage scenario en de verandering van de maatgevende afvoer van de Maas volgens W en W+ scenario zal ongeveer gelijk zijn aan de verandering in WB21 midden scenario. Zou je deze vuistregels toepassen op de KNMI06 scenario's dan resulteert dat in de getallen die in tabel 4b staan.

Tabel 4. Schatting van maatgevende afvoer (1/1250 jaar) Rijn (Lobith) en Maas (Borgharen) op basis van KNMI06 scenario.

A: Op basis van de vuistregel: toename van de maatgevende afvoer is evenredig aan de toename van de 10-daagse neerslagsom in het winterseizoen
B: Op basis van vergelijk tussen verandering afvoerregime WB21 en KNMI06 scenario's

A		Rijn (Lobith)	Maas (Borgharen)	B		Rijn (Lobith)	Maas (Borgharen)
2001		16000	3800	2001		16000	3800
2050	G	16640	3952	2050	G	16800	4000
	W	17280	4104		W	17600	4200
	G+	16960	4028		G+	16800	4000
	W+	17920	4256		W+	17600	4200
2100	G	17280	4104	2100	G	17600	4200
	W	18560	4408		W	19200	4550
	G+	17920	4256		G+	17600	4200
	W+	19840	4712		W+	19200	4550

Het verschil tussen beide schattingen is niet erg groot. Ten opzichte van de schattingen gebaseerd op WB21 (tabel 3) zijn de getallen voor de Rijn iets omhoog gegaan (WB 21 laag buiten beeld) en de Maas iets omlaag gegaan (WB 21 hoog buiten beeld). De beperkte waarde van deze constatering blijkt uit het gegeven dat de afvoer van de Maas met een terugkeertijd van 1250 jaar onlangs is herberekend op 4000 m^3/s (Diermanse, 2004b). Dit is gelijk aan het G scenario voor 2050! In 2002 en 2003 zijn er een aantal fikse hoogwaters geweest op de Maas die tot deze bijstelling hebben geleid. Deze observatie is eerder een aanleiding om de schattingen voor de Maas naar boven bij te stellen. Cruciaal hierbij is de afweging; beschouwen we de toename van het aantal hoogwater op de Maas over de afgelopen 30 jaar als natuurlijke variatie of als een reeds zichtbaar gevolg van klimaatverandering. Vooralsnog gaan we uit van het eerste.

Appendix 1c

Reference

Halmova1, D., Pekarova1,P., Pekar2, J., Meszaros1, I., STATISTICAL EVALUATION OF RUNOFF VOLUME FREQUENCIES OF THE DANUBE IN BRATISLAVA 1 Institute of Hydrology SAS Racianska 75, 831 02 Bratislava, Slovakia, 2 Department of Applied Mathematics and Statistics

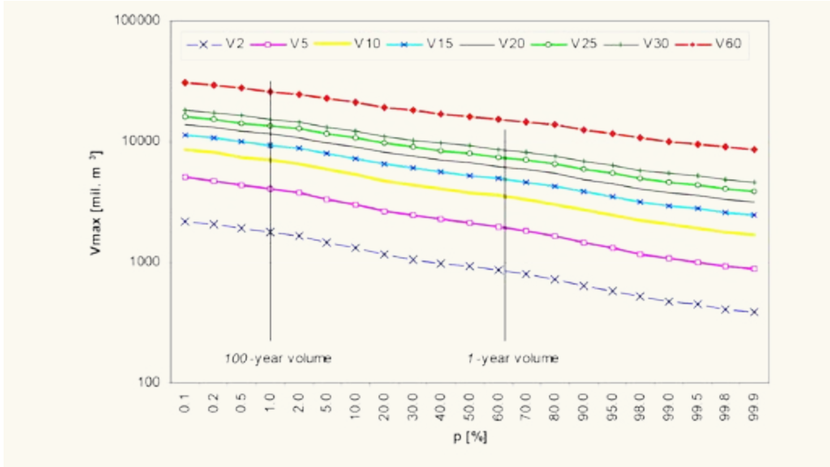

Figure 3. Theoretical cumulative probability density frequencies of the runoff volumes of the Danube at Bratislava, for runoff duration *t* equal to *t* = *2-*, *5-*, *10-*, *15-*, *20-*, *25-*, *30-*, and *60-* days, in logarithmic-probability scale.

Theoretical cumulative probability density frequencies (i.e. the exceedance probabilities) of the runoff volumes of the Danube in Bratislava, for runoff duration *t* = *2-*, *5-*, *10-*, *15-*, *20-*, *25-*, *30-*, and *60-* days, in logarithmic- probability scale are demonstrated in Figure 3.
From the results it follows (Table 1), that *100*-year maximum of *2*-day runoff volume (*V2*) is 1766 mil. m^3, *5*-day (*V5*) one is 4079 mil. m^3 and *10*-day (*V10*) one is 7004 mil. m^3.

Table 1. *T-year* peak flow *Qmax* [m^3s^{-1}] and the *T-year* runoff volumes *Vt* [million m^3] of the Danube at Bratislava within 1876–2005

N	1000	500	200	100	50	20	10	5	2	1
p %	0.1	0.2	0.5	1	2	4.9	9.5	18	39	63
Qmax [m^3s^{-1}]	12920	12195	11231	10494	9743	8740	7959	7147	6011	5089
V2	2189	2062	1894	1766	1636	1462	1327	1188	993	836
V5	5070	4773	4379	4079	3775	3370	3055	2730	2278	1915
V10	8566	8100	7480	7004	6519	5868	5359	4829	4084	3477
V15	11281	10706	9936	9343	8735	7916	7271	6596	5638	4848
V20	13874	13189	12271	11562	10834	9849	9073	8256	7093	6130
V25	16172	15402	14368	13567	12742	11625	10741	9807	8473	7362
V30	18350	17504	16364	15479	14567	13328	12345	11305	9811	8563
V60	30658	29352	27586	26209	24782	22833	21276	19618	17217	15187