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TRANSFERRING INTER-DISCIPLINARY FLOOD RECONSTRUCTION RESPONSES FROM JAPAN TO THE NETHERLANDS

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Lost in translation

Transferring inter-disciplinary flood reconstruction responses from Japan to the Netherlands

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Japan and the Netherlands have very different physical, historical and cultural contexts but they share a vulnerability to extreme flood related events and have, in both their (relatively) recent pasts, had to recover from such events: be they the floods of 1953 in the Netherlands or the tsunami that hit Japan's east coast in 2011. This paper describes the process and results of two workshops investigating flood reconstruction responses undertaken by students representing five disciplines at TU Delft in the Netherlands. A particular workshop method was employed to promote an interdisciplinary design process and then design responses investigated for the (very real) Japanese case were transferred to a hypothetical disaster scenario for Vlissingen, in the south of the Netherlands. The conclusions reached focused as much on the efficacy of the workshop method as the particular design proposals for both cases as well as on what was learnt via the comparison between Japanese and Dutch, contexts and reconstruction philosophies.

Introduction

The scale of the disaster that followed the magnitude nine earthquake and level two (over 15m high) tsunami off Japan's east coast on the 11th of March, 2011 is scarcely imaginable, as is the impact on the affected communities and on the nation as a whole. Were its dikes and coastal defences to fail, the Netherlands would face a disaster of similar proportions. This paper describes the process undertaken by a number of students representing five disciplines at TU Delft to investigate how multidisciplinary teams could work together in post-disaster reconstruction and how these working methods, as well as recovery solutions, might be applied to a hypothetical flood scenario in Vlissingen, the Netherlands. Two collaborative workshops were conducted - one in Vlissingen and one in Yuriage, near Sendai on Japan's east coast, north of Tokyo - in which the students split into two groups, individually prepared preferred proposals for the post-disaster reconstruction of each case study by discipline and then came together in an interdisciplinary setting (integrating and sharing disciplinary approaches and methods) to refine the designs.

In the introduction the physical settings and interdisciplinary working process are explained, as well as the purpose of this project from the perspective of both the process and the design components that both played an important role in this research. The method is split up into two sections in which the approach undertaken in the process and the design phase are explained step by step. Hereafter the results section presents an overview of the outcomes achieved both during the process and the design stages. The most important findings on both of these phases are summed up in the conclusion. The details and calculations of the designs mentioned in the results can be found in the appendix.
The paper will firstly introduce the physical settings and interdisciplinary working process used as well as the project objectives from the perspective of both the process and the design components that were equally important in this research. The design method is discussed over two sections that explain the approach taken in the process and design phases step by step. The outcomes of both the process and the design stages are then presented along with the most important findings summed up in the conclusion. Details, design plans and calculations referred to in the results section can be found in the appendix.

Physical setting

Yuriage. On March 11, 2011, Japan experienced a magnitude nine earthquake whose epicentre was 24 kilometres deep in the ocean 72 kilometres east of Tohoku (3) and that caused an enormous tsunami felt across the Pacific Ocean (Oskin, 2017). Waves heights of up to 40 metres destroyed most of the eastern coastline of Japan and in the Tohoku region, 560 square kilometres of land were inundated including up to 10 kilometres inland on the Sendai plain. Over 15,000 people died as a result of the tsunami and more than 2,500 people are still missing, not to mention the damage to property and infrastructure. The displaced population is estimated at around half a million and the damage at around US$ 200 billion (Oskin, 2017).

While Tohoku's inhabitants clearly recognise the Pacific Ocean as a source of potential catastrophes (particularly) after the 2011 Tohoku earthquake and tsunami, the ocean provides a source of income (fishing is the region's most important sector) and is a significant contributor to cultural identity (Japan Info,

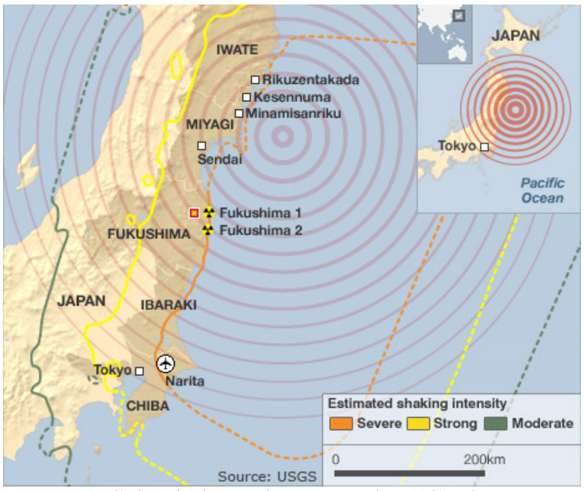

Figure 1. Seismic intensity per region (Geology Page, 2014).

2016). This area is in decline though due to internal migration to other Japanese cities and a shrinking and ageing population, socio-economic characteristics that add to the challenges of reconstruction planning.

This situation applies to Yuriage too. Yuriage is a town in the city of Natori, Miyagi prefecture. A coastal town, completely destroyed after the 2011 Tohoku earthquake and tsunami. Almost one thousand residents of Natori lost their lives and around 80% of the houses washed away (Murakami, Takimoto Pomonis, 2012). Pictures of Yuriage before and after the disaster are included in Appendix A1 of this paper. The site visit to Yuriage showed the current situation of the area, six years after the disaster took place (Appendix A2). New measures for tsunami defense fall into three categories (Figure 2):

1. Physical defenses: a coastal levee, coastal disaster prevention forests, and elevated roads.
2. Evacuation: Vertical evacuation facilities and evacuation routes.
3. Relocation: Moving residents to safer inland areas. evacuation roads.

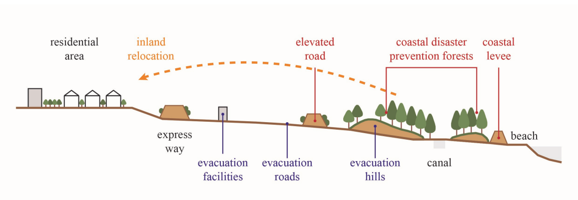

Figure 2. Proposed measures for tsunami defense.

Vlissingen. A large part of The Netherlands is located below sea level and today, these areas are protected by a complex series of dikes and large-scale, engineered flood defences such as Zeeland's deltaworks. These uncompromising measures were largely prompted by the 1953 floods and storm tide (caused by a combination of a high spring tide and severe storms) that resulted in a water level of more than 5.6 meters above mean sea level in some locations. A delta committee was appointed to prepare the Delta Plan proposals for thirteen structures (large scale dams, sluices and storm surge barriers) to protect the country from future flooding (Stichting Deltawerken Online, 2004). Vlissingen is located on the island of Walcheren, effectively separated from the mainland by a north south running canal with much of the town's peripheral landscapes below sea level, protected by coastal dikes, dune systems or sea locks. The fact that in October 1944, the allied forces bombed the dikes around Vlissingen to inundate the island and thus weaken the German position shows how vulnerable Vlissingen is to floods. Nowadays, Vlissingen is still vulnerable to coastal flooding, mainly due to sea level rise caused by climate change. However, the city's vulnerability to urban flooding is even more urgent. A visit to the municipality showed that the capacity of the current sewer system is insufficient. Rain showers are becoming more intense, causing sewage overflows and flooded streets. This demonstrates that Vlissingen is prone to several ways of flooding.

So while Vlissingen and Yuriage are both coastal, flood prone cities, they both derive a large part of their cultural identity and economic significance from the adjacent ocean or waterways and they both suffer from an ageing population (Gemeente Vlissingen, 2014; Tanaka, Shiozaki, Hokugo, & Bettencourt, 2012).

Figure 3. Dike breaches and flood in Zeeland, 1953 (Canon van Nederland, n.d.).

Interdisciplinary working process

True interdisciplinarity between different professional fields is still rare and is perhaps an unwieldy thing. This exercise gathered a number of Masters students from different disciplinary faculties at TU Delft to learn, understand and consequently develop a framework for collaboration on flood and tsunami reconstruction projects. The faculties in question were Urbanism (URB), Hydraulic Engineering (HYD), Geo-Sciences and Engineering (GEO), Water

Management (WM) and Transport Infrastructure and Logistics (TIL), although the TIL students were only involved in the workshop phases and not the design refinement phases. Difficulties inherent in cross disciplinary communication and collaboration were amplified by the variety of student backgrounds (representing as they did, five different nationalities) and the choice of the initial case of tsunami reconstruction in the town of Yuriage, Japan. This ensured that all students approached the project with similar levels of background knowledge as few had been to Japan before and none were very familiar with Japanese culture, lifestyles or planning and engineering approaches. Perhaps as a means to encourage easy communication, forge connections or simply as an act of academic whimsy, the two groups were separated by gender. This in effect though, might have added another layer of complexity to the evaluation of the chosen process as groups of males and females clearly work and relate differently to each other although it was interesting to note these differences when faced with a common workshop methodology. In this case, refining the process and experimental collaborative framework was the principal goal of the workshop and so, perhaps due to a lack of familiarity with the Japanese social and planning context, the short duration of the trip to Japan, some difficulties gathering informational and planning resources and lack of a clear set of project goals, the reconstruction proposals for the Yuriage condition were rather preliminary in nature. This represents an inversion of the usual state of affairs where the process is seen as subordinate to the end result and in this case, the plans for new approaches to tsunami reconstruction in Japan in general, and for the case of Yuriage in particular, were simply a means to test the chosen collaborative approach. This emphasis on a particular process might have been born out by the fact that the products of its second application for flood reconstruction in Vlissingen, were far more considered. This might have been the result of greater comfort with the particular interdisciplinary design framework or was perhaps a result of greater familiarity between team members (both personally and in terms of their professional requirements and preferences) and a Dutch context that the majority of participants were better acquainted with.

Purpose

Process. The intent of these workshops was first and foremost to investigate how a combination of relevant post-disaster planning disciplines might practically and effectively work together to produce proposals that are more than simply the sum of technical requirements. This required an emphasis on knowledge exchange between disciplines, building a common understanding and the application of a structured methodological approach in a (to most participants) foreign context. As such, the workshops were also a venue for international exchange of knowledge and experience between the Netherlands and Japan (hosted by Tohoku University, Sendai) in the fields of disaster prevention and recovery.

Given the unfamiliar context, disaster and cultural characteristics explored in the Tohoku workshop, its role was to act as a "learning ground" for Japanese design methods and approaches. Approaches that could be combined with Dutch practice and then applied to Vlissingen, the "test bed" for new collaborative and international design methods and ideas.

Design. Both countries have faced several water related disasters in the past and have implemented various mechanisms with which to protect themselves from storm surges (in the Dutch case) and tsunamis (in Japan). The japanese strategically approach the location of urban settlement and transport routes to minimise loss of life, ensure evacuation and reduce damage to critical infrastructure. This acceptance of risk is quite different to the Dutch approach where very little flood risk is entertained.

The physical (loss of life and infrastructure, including whole towns as was the case with Yuriage) and psychological impacts of the 2011 tsunami clearly permeate all of the subsequent decision making for how to go about the post-disaster reconstruction. The study group as outsiders were in no position to comprehend the intricacies of Japanese urban and social patterns but used a structured workshop approach to better understand current as well as historical mechanisms for flood and coastal protection. [1]

The exposure to unfamiliar disaster recovery (not to mention cultural and settlement) processes does prompt one to reconsider and be more critical of local practices and assumptions. Also, the use of extreme scenarios (hypothetical in the Netherlands but very real in Japan) allows a clean slate to consider alternative coastal management and settlement practices for Vlissingen: a more strategic approach to the city akin to the Japanese philosophy.

Methods

Process

The focus of the Yuriage workshops was to analyse multidisciplinary and interdisciplinary relationships between the five disciplines and were carried out according to the charrette method (Lennertz and Lutzenhiser, 2014). This process refers to any interactive session in which a group of participants draw up a solution to a given problem. It consists of multiple sessions in which the group is divided into sub-groups, to enhance dialogue and contribution of ideas. The diversity within the sub-groups is intended to stimulate

[1] Such as the planting of forests between the coast and settlements as wave attenuation devices as well as productive landscapes.

collaboration and promote the end goal of a shared solution, the goal for this specific project was to come up with an interdisciplinary design for both Yuriage (Japan) and Vlissingen (The Netherlands). The charrette model suggests a series of steps where disciplines are twinned in sub-group discussions and the size of each sub-group is gradually increased until in the final session, one large group discussion is held with all disciplines (figure 4).

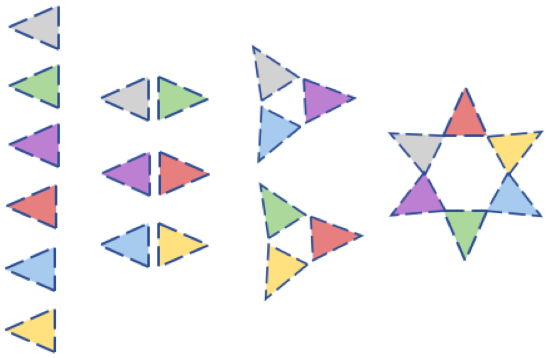

Figure 4. Schematic representation of the charette approach

The first stage of the process consisted of an monodisciplinary analysis (i.e. a process conducted separately by each discipline) where a range of intermediate solutions between two possible extreme approaches (a minimum and maximum case for how a space might be built or designed according to the standards and principles of each discipline) are identified along an axis of techniques or possible approaches, also defined by each discipline. The current and ideal reconstruction positions for Yuriage are both placed along this axis according to each disciplinary perspective (figure 5).

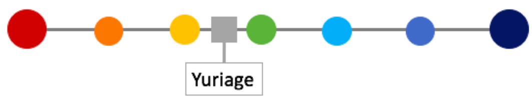

Figure 5. Visual example of end-product monodisciplinary analysis

The next step marked the beginning of the charrette process and consisted of pairing up disciplines to discuss their set limits and explain why certain choices were made. For example, how the axis extremities were chosen and what observations saw the placement of Yuriage at a specific point along the line. Communication was critical during this exercise as certain design concepts may need more in-depth explanations to ensure each discipline understands what is being expressed. For example, GEO intended to use geotextile fabrics but the benefits and limitations of such a (potentially unfamiliar) technique needs to be understood by all disciplines. This information exchange then took place between sub-groups of three disciplines before the final step of a group in which all disciplines were represented. The number of participants present at the workshop allowed for the creation of two design teams: Group A (made up of all females) and Group B (made up of all males), in which all disciplines were represented. Each group sought to forge connections between disciplines to identify how choices made by one discipline affected the others and reconcile these choices to produce an interdisciplinary design for Yuriage.

Design

For the Yuriage case, the focus was on the process of interdisciplinary cooperation that shaped a project vision that was elaborated via a conceptual design. This workshop process was repeated for the Vlissingen case but the masterplan and disciplinary aspects were developed further.

A number of design requirements were set for each case including that boundary conditions (provided by the government of Japan and The Netherlands (Rijkswaterstaat, 2014; NCPERD, 2017) are taken into account and that, for the Japan case:

- Level 1 protection line be provided against 1:100 year tsunamis, with no industry or residential areas to be built on the coastal side of this protection line
- Level 2 protection line be provided against 1:1000 year tsunamis, with industry, schools etc. located in this zone but with all residential uses landward of this defence line.

For the Vlissingen case in the Netherlands:

- Primary flood defences should protect against a 1:4000 year storm.
- Sea level rise should be accounted for as the city should be protected against conditions similar to the storm in 1953, with an additional 2 meters sea-level rise.

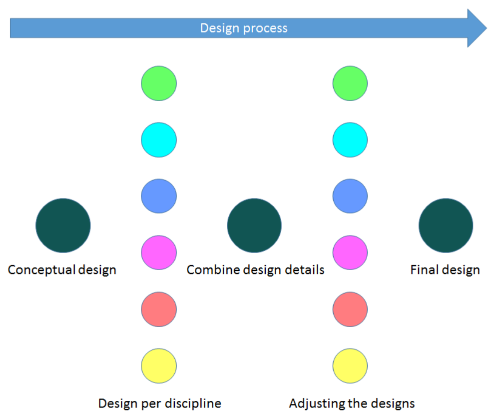

Figure 6. Schematic representation of the design process

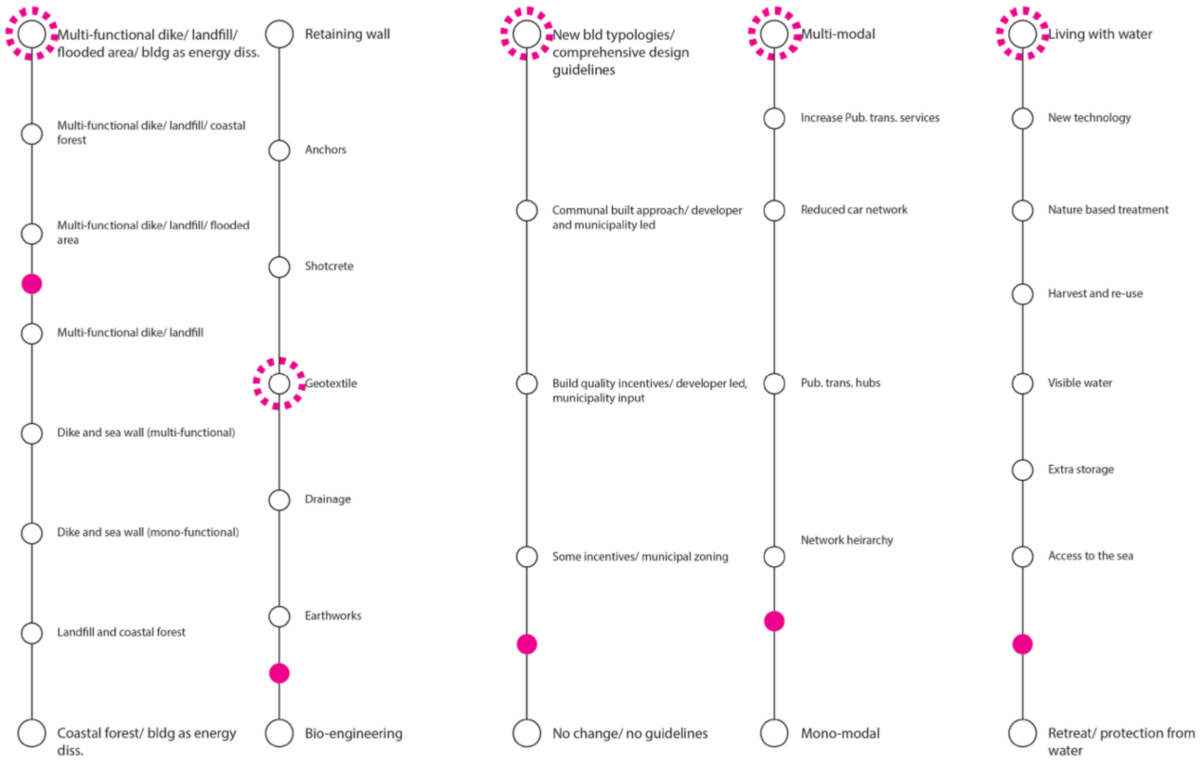

Figure 7. Axis of minimum / maximum scale per discipline with notional positions of current (pink dot) and preferred approaches (pink, dashed circle) for Yuriage

With these requirements in mind, all disciplines prepared a design most favourable from their perspective which were then combined into a single design incorporating the most appropriate elements of each disciplinary design. Once the conceptual designs were prepared, each discipline refined their part of the design to incorporate their calculations or more detailed designs. Disciplines then reconvened to check if all the component parts still fitted together and if not, the designs were adjusted. This process was repeated until all aspects of each disciplinary design were combined.

Results

Process

Scales of disciplinary measures . Prior to developing the interdisciplinary scopes, the study group visited the Yuriage site, were briefed by Natori municipal officials on the disaster and reconstruction process and held discussions with experts based at Tohoku university. This, along with each discipline's desktop analysis prior to the Japan trip, allowed the preparation of a scale appropriate approaches.
Each of the disciplines determined a range of measures to be applied in the Yuriage reconstruction plan and placed them in a scale ranging from the most desirable (placed on the top of the scale) to the least desirable (placed at the bottom). The resulting scale functioned as a guide during the discussions between the disciplines. It helped to create understanding about the different, sometimes opposing, disciplinary perspectives among the group members and to define the links between them.
In the HYD scale, soft measures were placed at one side of the scale, followed by hard measures and ending up to a combination of both hard and soft measures at the other side of the scale. Initially, this scale was developed differently, with only nature-based measures at the bottom (min) and only artificial at the top (max) with the preferred solution, a combination of all, in the middle. However, this led to misunderstandings and miscommunication with the other disciplines, so it was amended to the above mentioned scale from most to least preferred. GEO suggested a scale from engineered to nature-based solutions with measures going from retaining wall, anchors, shotcrete, geotextile, drainage to earthwork and bio engineering solutions. Interestingly, all disciplines except for GEO, defined the extremes of each scale as the least desirable combination of disciplinary measures (min) on the bottom and the most desired (max) at the top. The GEO scale placed engineered solutions at the top and nature-based solutions at the bottom of the scale.
URB defined their scope between the extremes of innovative urban renewal (placed at the top of the axis as a preferred/ maximum approach) and conventional urban recovery (at the bottom of the scale, suggesting a minimum approach). The maximum approach includes the creation of new building typologies and implementation of new technologies (renewable en-

ergy, green/blue structures), whereas the minimum approach is confined to bringing back almost exactly what was lost, with additional measures to safeguard against tsunamis but with no change to the traditional urban planning approach in place before the event.
The TIL scope was defined between multi-modal (the preferred/ maximum approach) and mono-modal mobility infrastructures. Finally, the WM scope lay between the extremes of living with water (the preferred/ maximum approach) and protection from water by retreating from the coast.
The scales per discipline, as described above, can be seen in figure 7. The pink dot suggests where Yuriage's position currently is as per each discipline's understanding, while the pink dotted circle suggests each discipline's preferred ("ideal") position for Yuriage in the reconstruction plan produced in the workshop. Yuriage's preferred position is at the top of the scale for all disciplines except for geo-engineering, a result of their alternate approach to the scale definition.

Connections between the disciplines. Group A sought to identify what influence the design decisions of a given discipline would have on each of the other disciplines and characterised these links as either weak, medium or strong. For example, if HYD requires a dyke for flood defense, it will strongly influence the GEO discipline (strong link) since the type of soil plays a role in the design. This decision however will not have much influence on TIL (weak link) while for WM, some drainage considerations may be required (medium link). See figure 8 for links between the five disciplines in which a bold line represents a strong link, a dashed line refers to a medium strength link and a dotted line represents a weak link.

Figure 8. Group A, final interdisciplinary links

Almost all the strong links operate in both directions (double strong link) as there is strong link from TIL to URB, and from URB to TIL, although the links between HYD and URB are the exception. Furthermore, the double strong links can be stretched out to form a line (figure 9). This line represents the links that should influence the design as well as suggest a sequence or starting point for design decisions. For example, HYD and GEO provide the engineering boundary safety conditions for the design and once this has been established, WM, URB and TIL can proceed to lay out their designs.

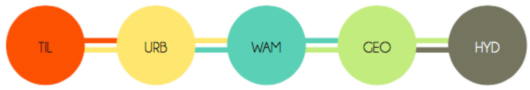

Figure 9. Group A, final 'strong' interdisciplinary links

These feedback loops are also important when making decisions within a discipline to understand how they will affect the other disciplines. In figure 10, the medium and strong links are shown as feedback loops that should be taken into account when preparing designs for Yuriage and Vlissingen. Interestingly, TIL's design decision process has little influence on the other disciplines (apart from the double strong link with URB) and GEO is the least affected by decisions made by other disciplines (excluding those of WAM and HYD).

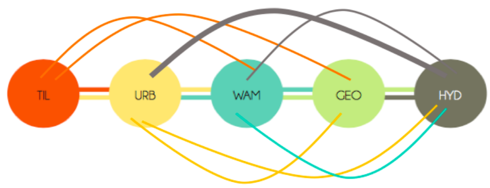

Figure 10. Group A, illustration of final 'medium' and 'strong' interdisciplinary links

Group B began by identifying solution sets through which disciplines could obtain co-benefits, so if a certain solution set overlapped with another discipline in terms of measures or goals, a line was drawn between these two sets. Intensive discussions between students determine if the influence was positive or not but the goal was to determine which disciplines most influenced the others and in which areas was cooperation possible. The links were at first established between twinned disciplines and later were combined in a single overview (figure 11).

Design

Description of Group A proposals. As the disaster scenario provided us with a tabula rasa, Group A decided to reduce the size of the town fabric. This promotes compact building blocks and multi-purpose spatial design in order to create a more climate resilient city. Furthermore, the new city core of Vlissingen will be located further inland. The footprint of the proposed area of aggregation covers a large part of the current town fabric, in order to preserve the emotional connection with this location. Locating the city core more inland allows us to utilise the wide strip along the coast and transform it into a natural flood defence area.

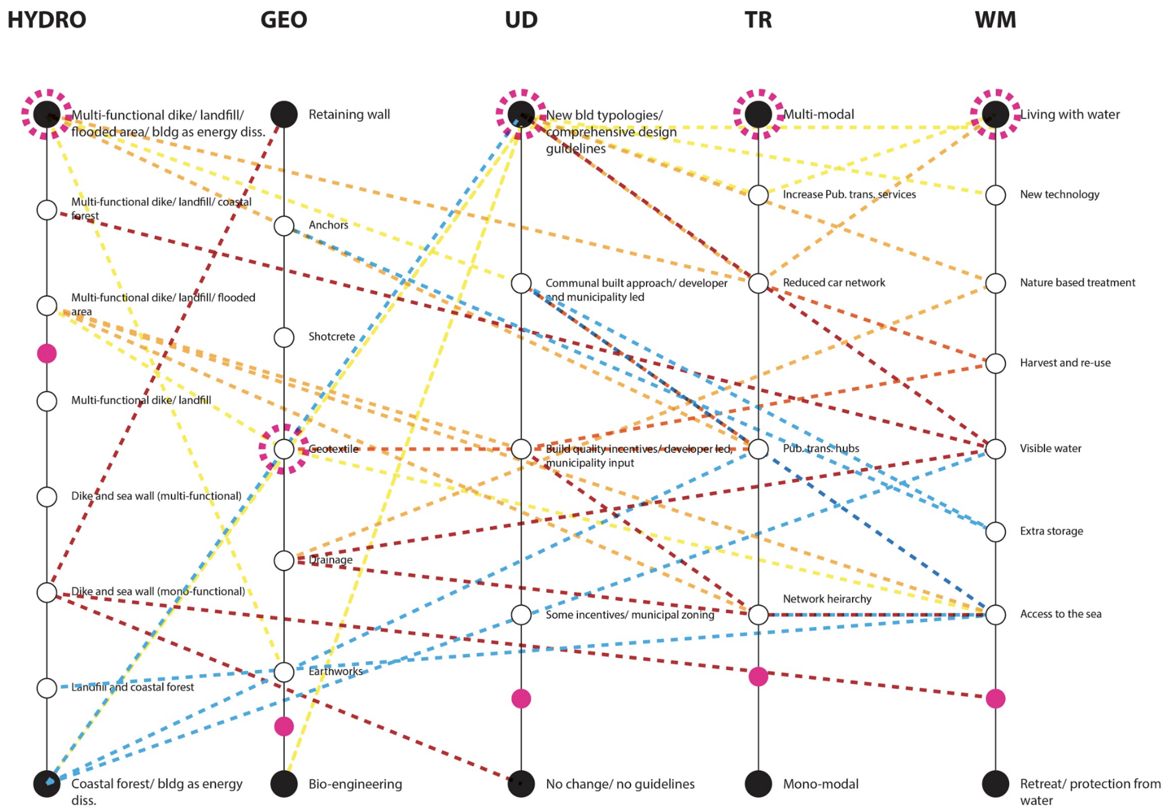

Figure 11. Group B, illustration of all interdisciplinary links

This natural flood defence area contains a coastal forest combined with dunes as a first layer of flood defence. The strip of green between the dunes and the city is suitable for seasonal and permanent flooding when the dunes are breached or overtopped. Furthermore, this vegetated area collects and infiltrates rainwater which flows from the city core. In order to include an extra layer of safety, the city core is elevated by four meters. The elevation can be created with debris from the former town fabric. The green landscape around the city can be used for agricultural purposes and is suitable for seasonal flooding too.

When it comes to the experience of the new city, the connection between the city and the sea will be emphasised. Physically, this relation is present in the form of elevated walkways leading from the boulevard towards the beach. These walkways offer attractive routes for pedestrians to discover the new landscape. The skyline of Vlissingen will also be restored to offer a sea view to the residents. Water will play a role within the city as well, as infiltration and storage capacity will be added to the streetscape in the form of water squares, urban infiltration strips and blue-green roofs on buildings.

Description of Group B proposals. While the disaster scenario that we were to contend with and the post-disaster reconstruction we were to plan for theoretically allowed us a clear slate (after the town had been flooded by a catastrophic storm surge), Group B chose to largely re-build on the current town fabric. This was under the assumption that aspects of the town layout and infrastructure might survive but also that the cultural connections with the current townsite were worthy of retention: the very same sentiments that saw the reconstruction of Yuriage in the same geographical location as the original village.

The urban landscape of Vlissingen was to be approached according to zones of landuse typology and flood management character(see figure 13 below and appendix E2). These landuse zones were essentially dictated by the previous settlement typology (city centre, suburban, peripheral and agricultural landscapes) as well as by the factor likely to most indicate flood vulnerability, a site's elevation. Coastal protection requirements suggested a raising of the coastal dike to such an extent that the connection between the adjacent city centre and the coastal edge would be substantially obstructed. In order to mitigate the impacts of this, the dike was proposed to also play a water storage and public service provision role (car parking and other social functions) as well as contain a widened zone of public space that both moderated the change in level from the top of the dike back down to the adjacent city centre but also promoted sightlines and public accessibility.

The city centre was to be largely reconstructed albeit with a slight rise in elevation to reduce elevation dis-

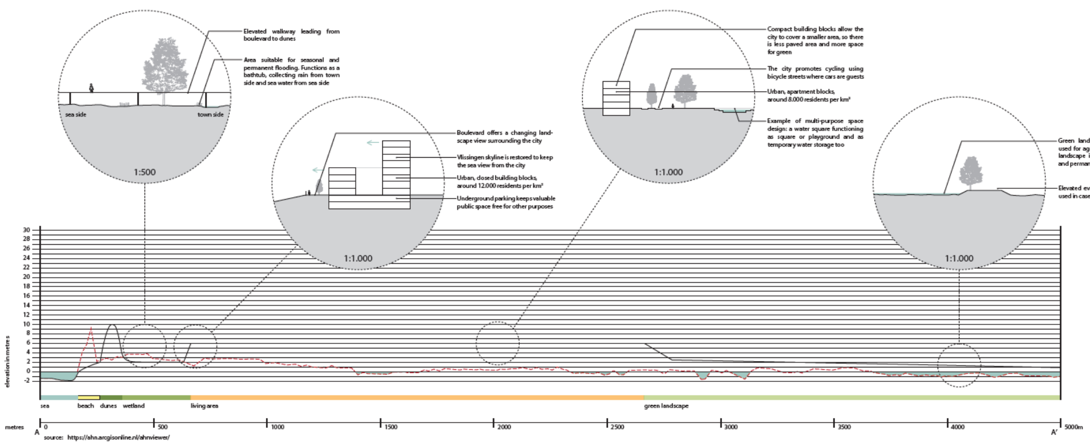

Figure 12. Design proposal group A, illustrated section

crepancies and facilitate drainage towards water storage or infiltration areas. While this area (where most of the residents would continue to live) would be some of the highest in the new town site, there would need to be a greater acceptance of the risk of future flooding (an acceptance facilitated by the improved evacuation infrastructure and by new building typologies that might allow partial flooding of the ground floors without rendering the site uninhabitable).

The most drastic change was proposed for the broad, low lying agricultural and peripheral lands that are at present maintained to the same flood protection standards as the city centre. These areas would be allowed to be periodically flooded (and excavated as necessary to provide fill for artificially elevated areas elsewhere) as a venue for flood attenuation, redirection and water storage, and the current traditional land use amended to the propagation of saline crops or the creation of natural habitat. Essentially the urban qualities of these peripheral areas are sacrificed to better secure the highly populated areas on the slightly elevated plinth that contains the city centre. Between these two zones lie an intermediary landuse on an area of steeper slopes that is intended to quickly carry away any floodwaters or excess stormwater from the city centre to the low-lying flood plains. This area might still be populated as long as the building typologies and public space design allow for this primary drainage function (housing on stilts and green corridors that double as uninterrupted, high capacity overland flow paths etc.).

Design steps per discipline

Role of hydraulic discipline in the final design. The main scope of the hydraulic discipline was to provide the boundary conditions for the design. For this scope raw data were processed by simulating 1953 Vlissingen storm conditions in SWAN software (Appendix C.1). Additionally, calculations were also made to define the final width (for Group A) and final level (for Group B) of the first line of defence. (Appendix C2, C3).

Hydraulics played more of a controlling role in the determination of the final design by and ensuring that it complies with the safety and flood risk mitigation requirements. Interaction was mainly with URB and GEO by sharing inputs and receiving outputs, in order to find the optimal location, dimensions and layout of the protection works. Limits dictated by the boundary conditions (water levels and wave heights) had to be set and the other disciplines had to adjust their design to take into account these limits. However, there was the effort not to set very strict limits, in order to leave space for the fruitful input of the other disciplines. As discovered during the process, the hydraulic discipline leans more towards the technology than the human side and its scale of application is meso to macro, making it very broad.

Through the design process in Vlissingen, it became clear what principals need to be taken into account. Safety is the first priority, but socioeconomic and environmental factors should also be incorporated in the design to ensure it becomes more sustainable and resilient. The reconstruction time turned out to be of vital importance when designing, as a long reconstruction time would lead to people settling elsewhere and, thus, being unwilling to return to the place in question.

Role of water management in the final design. From a water management perspective, incorporating climate resilient urban drainage solutions is the most important aspect. Several climate change scenarios predict an increase in rainfall intensities and for Vlissingen, hourly rainfall statistics were derived using 1990-2017 figures. Depth-Duration-Frequency and Intensity-Duration-Frequency curves were determined by using an annual maxima analysis and the Gumbell distribution. These calculation can be found in Appendix D.

Furthermore, the storage capacity required in the area was calculated with an urban drainage model, one of

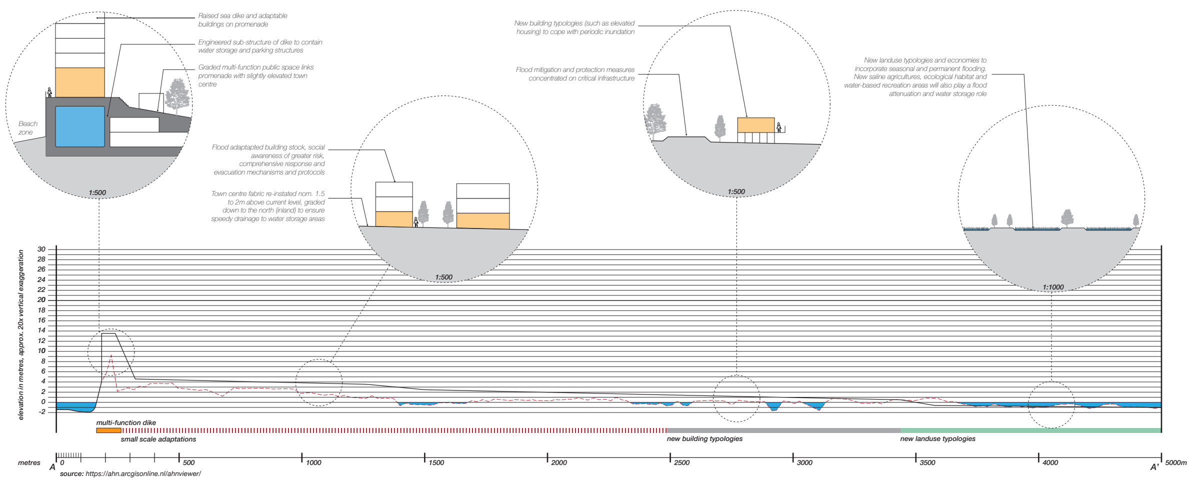

Figure 13. Design proposal group B, illustrated section

the most important inputs for which is the land use and runoff coefficient. This information was mainly derived from the urban design proposals.

The storage capacity is expressed in a Storage-Discharge-Frequency curve which shows the amount of cubic meters of water storage per hectare needed for a corresponding return period. The required water storage leads to a feedback loop for the urban design. For a return period of 25 years, a storage capacity of 225m3/ha is needed that corresponds with a spatial demand of approximately 5.6% of Vlissingen's total area.

Role of Geo-Engineering in the final design. The geotechnical part of the design is the design and safety check of the primary flood defences. Group A has a natural flood defense barrier that demands a particular design for the profile of the dunes. This was done using Dutch regulations (ENW, 2006) and the sea conditions calculated by HYD. These regulations and conditions required a beach and dune width of around 450 meters and a height of 12,5 meters. These dimensions are used for the final design(See appendix B1 for the calculations).

Group B's design uses a dyke as primary flood defence which is also designed according to the Dutch regulations (TAW, 1999) with the height determined by HYD. To limit the amount of overtopping, the height of the dyke should be almost 14 meter. With slopes of 1:5 and 1:3 this gives a width of 70 meters. The stability of the dyke was confirmed with D-Geo stability and is determined safe in different situations (See appendix B2 for the calculations).

Conclusion

Process

True interdisciplinarity is still a challenge in today's projects and often represents more a sum of multidisciplinary approaches. The main purpose of the workshops was to investigate how several disciplines could effectively work together and whether a framework for interdisciplinary working could be set up and transferred to the Netherlands. Yuriage therefore, acted as a learning ground for the more detailed design in Vlissingen.

During the charrette workshop sessions, collaboration is encouraged by starting with smaller sub-groups. Intensive discussion between disciplines based on theoretical background before focussing on design aspects and solutions stimulated true interdisciplinary solutions and visions. The principal challenge in the charrette approach was to adjust the scope of solution sets between disciplines. More technical focussed disciplines such as HYD and GEO were particularly difficult to match with other disciplines that might have had a broader scope of interests. Clearly expressing how these disciplines affect each other was difficult and these problems were experienced by both groups. For disciplines where the interconnectivity was more clear, speedy and intensive collaboration was more possible from the outset.

The designs for Yuriage clearly influenced those for Vlissingen and this is likely a result of the use of the same interdisciplinary working framework. The established links between disciplines acted as a guideline in the technical elaboration and several feedback loops can be distinguished which were used by the group to fine-tune the technical details of the design in Vlissingen.

Design

The design produced for Vlissingen managed to incorporate most of the techniques the group learned during the Japan workshops. In contrary to the dominant Dutch approach of focusing mainly on the first line of defence, attention was given to multilayer safety with a larger scale, "broader" design that utilises a range of measures located more inland. The Japanese concept of elevated land proved useful in Vlissingen by suggesting key parts of the urban environment are placed at a higher level to ensure that they remain relatively safe, even if a breach of the primary defences occurs. Areas intended to flood are also used in Vlissingen to store part of the storm surge: by Group B in the redevelopment hinterland and by Group A between the dunes and the city centre. This not only makes the water volume more manageable but also creates a new topology where the Dutch notion of "Building with Nature" can be applied in this new brackish environment.

In Japan, strict attention is paid to emergency evacuation measures where disasters might occur with minimal time for evacuation, sometimes less than an hour. Japanese techniques might be applied in Vlissingen but in a more lenient manner, since the Dutch disaster timeframes are in the order of days before the arrival of a storm surge. In this respect, there is no need for a comprehensive network to facilitate immediate evacuation (as is the case for Yuriage) but an additional route out of the city (in addition to the single existing route) should be considered.

Concerning the primary defence, the Japanese technique of a high, wide sea wall is also proposed for Vlissingen but in a form more integrated into the built environment, as a multifunctional dike in accordance with Dutch philosophy. Thus, this technique is transferable to the Dutch context after some adaptations. The Japanese knowledge of scour protection can also be utilised, so in the case of overtopping a complete, uncontrolled failure of the structure will be avoided. However, hard materials predominantly used in Japan are replaced by grass in the Vlissingen case to create a more natural, environmentally integrated result. The concepts can be transferred, however, the types of materials used in the design are less transferable, as concrete is predominantly used in Japan whereas soil, for the structure and grass, for the slope protection, are used in the Vlissingen design. This choice is determined by the local availability of materials and unique circumstances of each place. The utilization of traditional techniques is another lesson learned from Japan, where the tendency to respect tradition is widespread also in tsunami protection philosophy, as seen by the incorporation of old canals and coastal forest in Yuriage's tsunami defense system. Therefore, in a similar way the revival of the dike in front of the promenade, already existing before the imaginary disaster in Vlissingen, constitutes the incorporation in the design of a traditional element of the city.

Although far more conceptual than Vlissingen, the design for Yuriage might apply Dutch concepts. The choice of dunes over hard dike measures in Group B's design and the use of a beach in front of the coastal levees to create more room for recreation by Group A are approaches important for Dutch urban planning, yet not sufficiently utilised in Japan. Interestingly both final designs for Vlissingen incorporated flood resilient techniques encountered during the trip in Japan, partly this may have been implemented in a unconscious manner. For example, Group A used the elevation of land and retreat from the coastline, which was also incorporated in the reconstruction plans of Yuriage. However, in contrast to Yuiage, instead of using mainly concrete structures, this space was designed with implementation of natural elements such as sand dunes and vegetation. In a way this could be compared to the concept of a coastal forest, which is an ancient Japanese flood defence technique. Group B's design for Vlissingen maintained the characteristic high-rise building boulevard of this city, but gave it a multifunctional use of flood defence and recreation. Similarly, in Yuriage the reconstruction will include a high sea wall, however this structure will not have a second purpose.

The Dutch and Japanese flood protection approaches may vary in applied techniques, materials and design choices but there are aspects in both approaches that could work well together and provide future solutions for resilient cities. There is much the Dutch can learn from the Japanese approach, in particular in terms of evacuation, but it is important to remember that the disaster events which both countries deal with are different in both time, magnitude and after-effects. However, both deal with severe flooding and both have histories of flooding, so recognise how serious these threats are. The final designs for the city of Vlissingen integrated the knowledge acquired from both the techniques used in the Netherlands and those acquired in Yuriage. The combination of traditional Japanese techniques, such as coastal forests or an energy dissipation canal, might allow for an "intercontinental design", where the positive aspects of both Dutch and Japanese flood protection approaches are present.

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Appendix A
Yuriage

Appendix A1: Before and after

Yuriage and surroundings, 2008 (Maptd, 2011)

Yuriage and surroundings, 2011 (Maptd, 2011)

Yuriage, 2008 (The Journal, 2011)

Yuriage, 2011 (The Journal, 2011)

Appendix A2: Site visit Yuriage

Memorial monument

Hiyori Hill

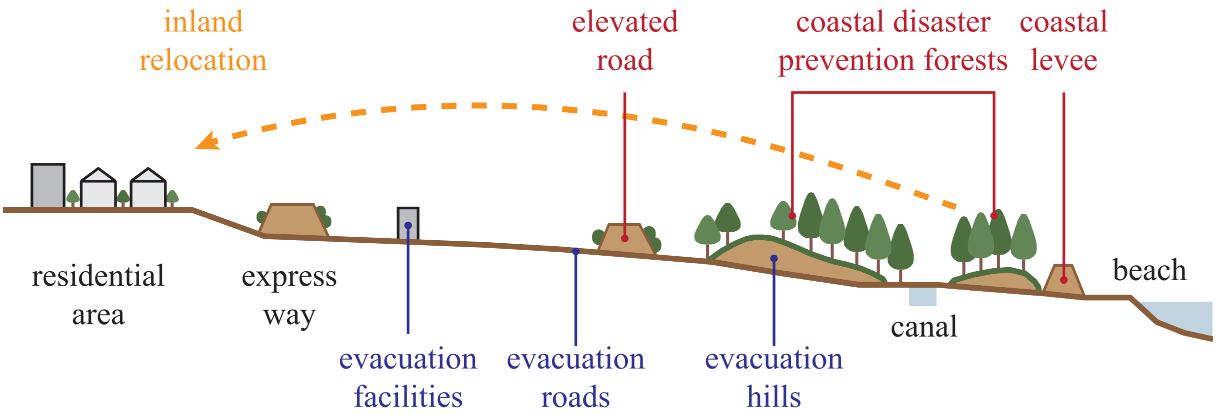
New residential area

New apartment building

Plans for Yuriage

Remaining foundation

Appendix A3: Measures for tsunami defense



Three types of measures for tsunami defense:
1. Multiple defenses: Defending against a tsunami with multiple countermeasures (a coastal levee, coastal disaster prevention forests, and elevated roads).
2. Evacuation: Running away from a tsunami using evacuation facilities and evacuation roads.
3. Relocation: Moving the residents to safer inland areas.


Coastal disaster prevention forest (OISCA, 2011)


Reconstruction on elevated landfill


Coastal levee (The Asahi Shimbun, 2017)

Indication evacuation building

Appendix B
Geo-Engineering

Appendix B1: Design of the dunes

For the design of group A is the primary flood defense made up out of dunes. The dunes are designed according to the Dutch design codes (ENW, 2007). To determine the width, shape and height of the dunes the "afslagprofiel" is calculated. Afslagprofiel is the Dutch term for the profile that the dunes have after a storm. During a storm the dunes gets eroded and that sand is places somewhere else. The Afslagprofiel should be placed in the dunes so that there is equilibrium between the eroded zone and the sedation zone (figure D3. The afslagprofiel is calculated with the formulas 1, 2 & 3.

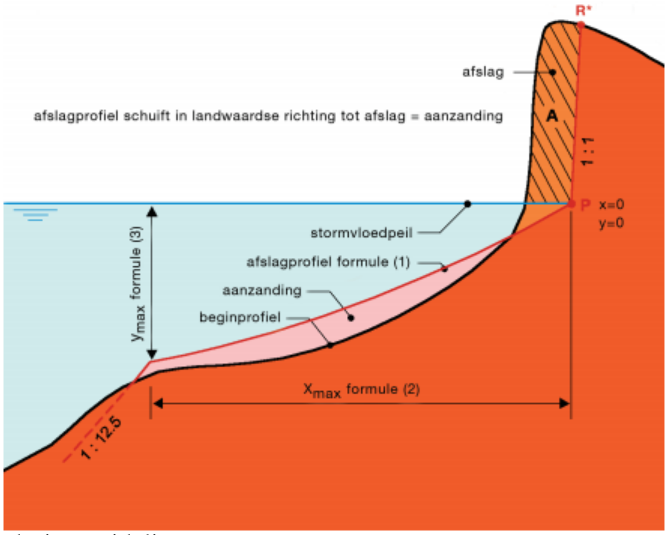


Figure B1. Afslagprofiel design guidelines

$$\left(\frac{7.6}{H_{0s}}\right)y = 0.4714\left[\left(\frac{7.6}{H_{0s}}\right)^{1.28}\left(\frac{12}{T_p}\right)^{0.45}\left(\frac{w}{0.0268}\right)^{0.56} x + 18\right]^{0.5} - 2.0 \tag{1}$$

$$x_{max} = 250\left(\frac{H_{0s}}{7.6}\right)^{1.28}\left(\frac{0.0268}{w}\right)^{0.56} \tag{2}$$

$$y_{max} = \left[0.4714\left[250\left(\frac{12}{T_p}\right)^{0.45} + 18\right] - 20\right]\left(\frac{H_{0s}}{7.6}\right) \tag{3}$$

The values used for these calculations are determined by the hydraulic student (Appendix C1). The used values are:

H_{0s}	=	5 m
T_p	=	12 s
w	=	0.35 m/s
Stromlevel	=	9.1 m

When filling in these values in the formulas gives a profile shown in figure B2. The height of the dunes need to be over 12 meter. The width of the beach is around 250 meters when the sea level is around NAP. The erosion during the storm is 90 meters (See hydraulic report), so the dunes should be at least 190 meters. To meet the Dutch codes standards the dunes should have a certain profile left after the storm (figure B3). This gives an extra width of around the 20 meters, so the total width of the dunes is 210 meters. So the total width of the flood defence (beach + dunes) is 450 meters.

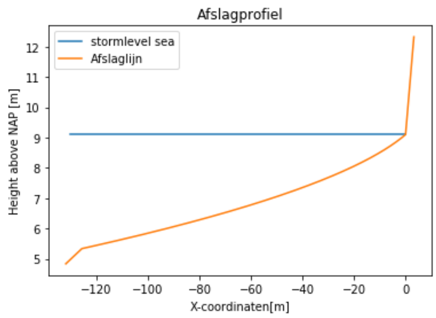


Figure B2. Afslagprofiel for Vlissingen

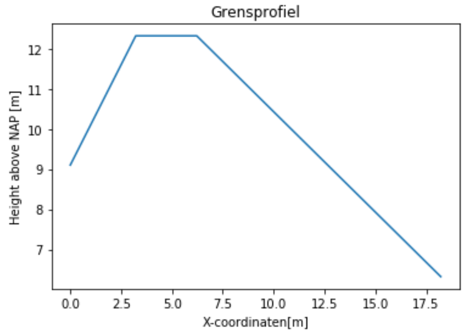


Figure B3. Minimum profile after the storm

Appendix B2: Design of the dike

For the design of group B is decided for a dike as the flood defense. Again are the Dutch design codes used for the design of this flood defense. The height of the dike is determined by the hydraulics, so that there is not more than the allowed amount of overtopping. The height is set at 13.84 m. The outer slope for a sea dike cannot be steeper than 1:5 and the outer slope steeper than 1:3 (TAW,1999). These demands together determine the geometry of the dike (figure B4). The dike is build up out of a sand core with a 3 meters thick layer of clay as top layer.

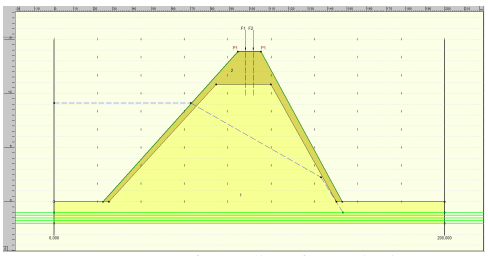


Figure B4. Geometry of the dike for Vlissingen
Light yellow = sand, Dark yellow = clay

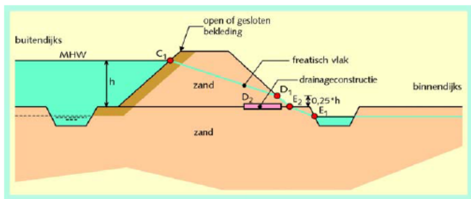


Figure B5. Phreatic surface in a dike with clay cover (TAW, 2004)

To determine the stability of the dike the program D-Geo Stability from Deltares is used. For the calculations is the phreatic surface in the dike very important. This is determined with the Dutch technical report for water stresses in dikes (figure B5). The subsurface in Vlissingen exist for the most part out of sand (figure B6), so the model in simplified by only assuming sand under the dike. The load on top of the dike consists out of a permanent uniform load, which is the permanent load of the road of 10 kN/m2, and 2 variable line loads for traffic driving on the dike, which in the worst case are 2 trucks of 400 kN. The soil properties used for the dike are noted in table B1.

Table B1
Soil properties

	Clay	**Sand**
γ_{wet}	14 kN/m^2	20 kN/m^2
γ_{dry}	14 kN/m^2	18 kN/m^2
Cohesion	10 kN/m^2	0 kN/m^2
Friction angle	25 deg	33 deg

D-Geo stability calculates if the dike is stable for a pre-determined variety of slip surfaces. The situation during storm with a sea-level of 9.1 meters has a factor of safety above 1.5 for all the slip surfaces. When the sea level is higher than the expected 9.1 meters, the slopes are still safe until a sea-level of 12 meters.

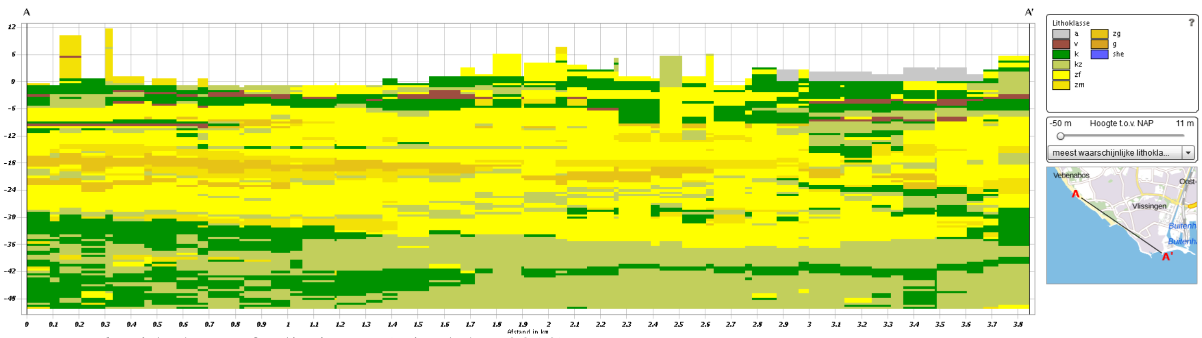


Figure B6. Lithology of Vlissingen (Dinoloket,2018)

Appendix C
Hydraulic Engineering

Appendix B1: Boundary conditions

Still water level. Hypothesis: The disaster scenario, after which the reconstruction will follow, is that Vlissingen is destroyed by the 1953 storm surge. This reached a maximum of 3.65 m in the Wadden Zee and about 3 m in Vlissingen. Another part of the hypothesis is that the storm surge occurs concurrently with the "king tide", the annual maximum tide, which has an amplitude of 2.64 m. An additional 2 m are added to include sea level rise, which is not only associated with the rise of water level, but also with the potential more frequent presence of hurricanes in the Northern hemisphere and the associated increased water levels and wave heights (Haarsma, 2013). By adding all the above, the still water level adds up to 7.64 m MSL nearshore.

Nearshore Wave Height from SWAN Software. Subsequently, the significant wave height nearshore is calculated by using the SWAN software.

SWAN inputs:
As offshore starting point, the point with coordinates 51°44 N, 1°58 E is chosen. At this point the offshore waves had the following characteristics during the 1953 storm (J. Wolf, R.A. Flather, 2005) : H_s =5 m and T_p =14 s. The wind speed was u_w =20 m/s and the direction is chosen as 287 deg N, such that it is the same with the wave direction, thus, amplifying the wave height and giving a more critical result. The direction of normal to the coast is 41 deg N. Bathymetry was taken from Navionics website. A picture of the bathymetry map from Navionics is shown in figure C1.

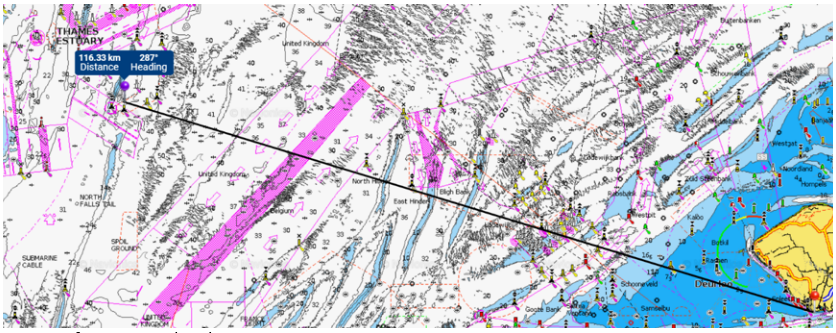


Figure C1. Bathymetry from Navionics

The still water level (SWL) nearshore is 7.64 m, as described above. The inputs used in SWAN are summarized below.

H_m0	=	5 m
T_p	=	14 s
Mean wave direction	=	287 ° N
Water level	=	7.64 m
Wind velocity	=	20 m/s
Wind direction	=	287 ° N

The boundary conditions and bathymetry inserted in SWAN, as well as the direction of the coast, waves and wind can be seen in figures C2, C3 and C4 respectively.

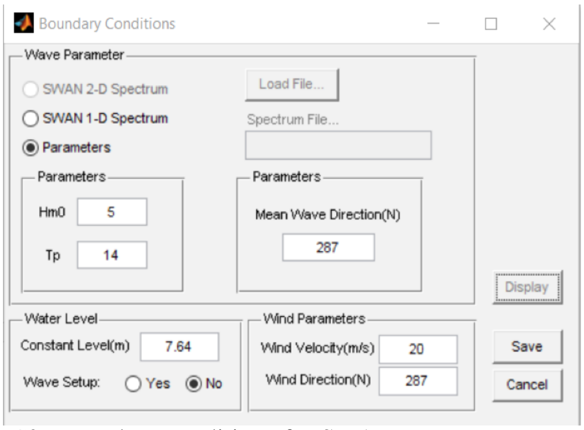


Figure C2. Boundary conditions for SWAN

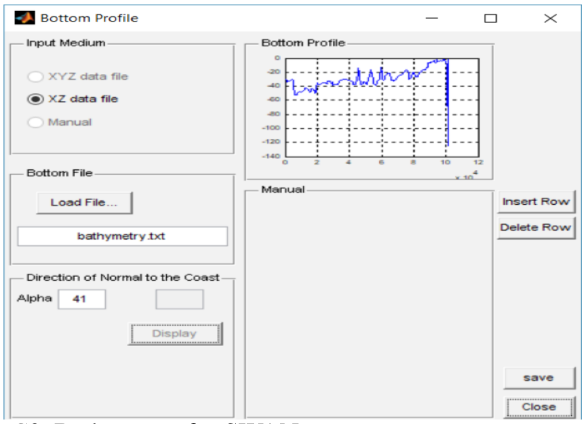


Figure C3. Bathymetry for SWAN

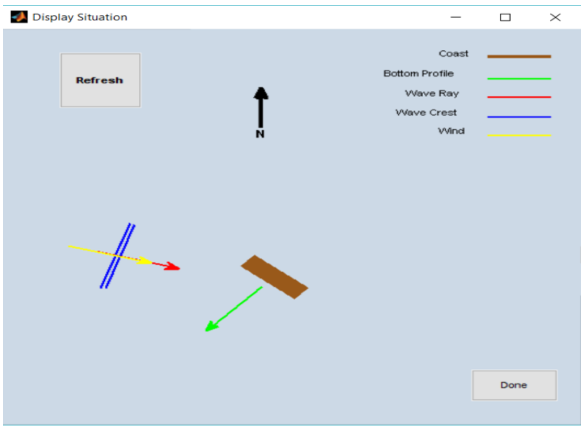


Figure C4. Visualization SWAN model

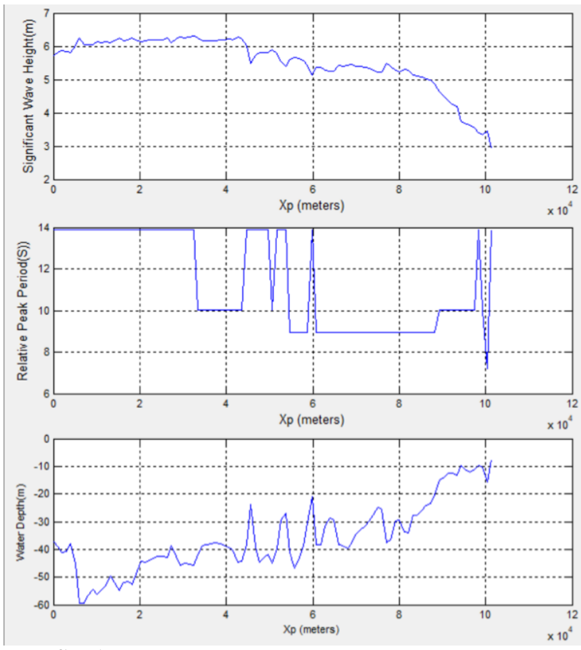


Figure C5. SWAN output

By using SWAN simulation, nearshore H_s and T_p of 2.92 m and 13.89 s were found. The output from SWAN can be seen in figure C5, where the significant wave height, the peak period and the bathymetry from the offshore point to the nearshore point near Vlissingen are shown.

Appendix B2: Hydraulic calculations for Group A (Girls) design - Dune erosion

Concerning the design of Group A, the minimum required dune width is determined. For this purpose a dune erosion calculation on the design provided by the geo-engineering discipline is performed. The dune retreat during the storm is calculated by using the Bruun rule (P. Bruun,1962). It is assumed that the erosion profile is the same as the pre-storm profile equilibrium profile, but the elevation of the storm surge level is used instead of the MSL. Thus, a first order estimate of the dune retreat during the storm (episodic event) is made: Dune retreat = (L*SSL)/(h+d) = 190 m, with L =beach width between top of duneface to MSL = 250 m. This value is an input by the geo-engineering discipline. (Appendix A1) SSL = storm surge level = 7.64 +2.92/2 = 9.1 m and h + d = dune height above MSL = 12 m (input from geo-engineering) Thus, dunes with width of at least 190 m should be present to resist the storm erosion and prevent Vlissingen from flooding.

Appendix B3: Hydraulic calculations for Group B (Boys) design - Dike overtopping

In order to determine the final height of the multifunctional dike proposed by Group B, an overtopping calculation (EurOtop, 2016) is made with the formula 4.

$$\frac{q}{\sqrt{gH_{m0}^3}} = \frac{0.067}{\sqrt{tan\alpha}}\gamma_b\xi_{m-1,0}exp(4.75\frac{R_c}{\xi_{m-1,0}H_{m0}\gamma_b\gamma_f\gamma_\beta\gamma_v} \tag{4}$$

With H_{m0} = $2.92m$ = wave height near dike.
tanα = seaward dike slope=0.2 (input from geotechnical design).
γ_β = 1 (no berm).
γ_f = 1 (grass at outer slope that has a good aesthetic result and can be restored after the storm).
γ_β = 1 (waves assumed to be perpendicular to dike).
$\xi_{m-1,0}$ =tan$\alpha/s^{0.5}$ =1.85 with s=2 $\pi H_{m0}^3/(gT_0^2)$ = 0.012
γ_v =1-0.47*$L_{promenade}/L_{m-1,0}$ = 0.91
$L_{promenade}$ = 50 m and $L_{m-1,0}$ =gT_0^2 /(2π) with T_0 = 13.89 s, g=9.81 m/s^2

There will be a promenade at the landward side of the dike that will incorporate multiple uses, such as recreation. This element belongs to the traditional landscape of Vlissingen and will be restored during the reconstruction. The restoration of traditional elements that can also function as buffer zones for the dissipation of wave energy is a lesson learned from Yuriage, where the coastal forest and the canal are indispensable parts of the local identity that also serve as tsunami protection measures. By choosing the desired value for the overtopping discharge q, the crest height of the dike above the storm water level, R_c , is determined.

The allowable overtopping discharge (q) depends on the land use (presence of buildings, promenade, people's presence) behind the dike. The question to be answered is how much overtopping can be allowed.

1. Minimum overtopping allowed
   If maximum protection against overtopping is chosen, then for H=2.92 m and q 1 l/s/m, the final dike height is over 16 m MSL, which is a very conservative estimate and will hinder access and view to the sea, as well as different land uses at the land side of the dike not leaving enough room for multipurpose planning (undesirable for other disciplines, especially urbanism and water management).

2. Certain overtopping volume allowed
   In case a higher overtopping discharge is allowed, q 10 l/s/m, the final dike height is 13.84 m MSL. That value was chosen as a best option by all disciplines, since it guarantees a high level of safety, which is very important for the hydraulic discipline, but also does not hinder the goals of the other disciplines. However, other measures should be utilized to protect human life and property. Those measures include elevated buildings, sacrificial first floors and moveable storm barriers integrated in the urban environment to ensure that the structural integrity of the structures will be maintained. Additionally, spatial and emergency evacuations measures will be used to ensure that people and vehicles are not present when the storm hits and the risk of loss of life is minimized. Cooperation with other disciplines is necessary to result to an interdisciplinary design of the above different measures and to ensure that they work well together.

Regarding the scouring at the inner slope, grass cover at the inner slope of dikes has no significant damage for overtopping of 30 l/s/m and for an interval of 6 hours. Thus, since the overtopping volume will be less than 10 l/s/m, as a first estimate, in the absence of time for more detailed research, grass can be used at the inner slope of the dike in Vlissingen. Better results can be achieved by using reinforced grass. Further combined study from both the hydraulic and geoengineering discipline can produce more detailed results for that matter. Attention should be paid to the points of transitions, if a combination of different materials for the slope cover are chosen.

Appendix B4: Methods used for the design

For the design for Vlissingen, the following methods were used by the hydraulic discipline:

1. Hand calculations to determine the still water level nearshore Vlissingen, in which information about the storm surge in 1953, the annual maximum tide and the effect of Sea Level Rise where added.

2. Numerical wave modelling SWAN to calculate the wave height nearshore Vlissingen on top of the still water level described above. With the above two methods, the boundary conditions for the Group A and B's design were defined. After those were set, the hydraulic design parameters of the primary defenses present in both designs were determined by utilizing the methods mentioned below:

3. For the determination of the dune width in Group A's design, an erosion calculation using the Bruun rule was performed.

4. For Group B's design, the formula from the Overtopping Manual was used. An upper limit of the overtopping discharge was chosen and the required dike height resulted. For the inner slope material to avoid scouring, no quantitative calculation was made, but grass was chosen conceptually based on the study "Erosion strength of inner slopes of dikes against wave overtopping - Preliminary conclusions after two years of testing with the Wave Overtopping Simulator, August 2008", in which physical modelling was used.

Appendix D
Watermanagement

To calculate needed storage capacities for pluvial water a rainfall analysis is needed. Currently one of the approaches is to use rainfall statistics from De Bilt, in the center of the Netherlands, and add 10% for coastal effects and another 10% to comply with a climate change scenario for 2050 (Smits et al (2004), KNMI (2006)). For the WM design rainfall statistics from measurements in Vlissingen instead of De Bilt are used. The same 10% surplus is used for the climate change scenario.

Hourly data from 1991 to 2018 is downloaded from the Royal Netherlands Meteorological Institute (KNMI, 2018). For every year the maximum 1-, 2-,8-,12-, 24-, 48-hourly rainfall in mm is derived. Using the Gumbel distribution an extreme value analysis is performed. Maximum likelihood estimators X_0 and β are calculated. For every duration period and return period the corresponding rainfall depth is calculated, using equation 5.

$$\beta = \frac{1}{n}\sum_{i=1}^{n}(x_i) - \frac{\sum_{i=1}^{n} x_i * \exp\left(\frac{-x_i}{\beta}\right)}{\sum_{i=1}^{n} \exp\left(\frac{-x_i}{\beta}\right)} \qquad Xo = -\beta * \ln\left(\frac{1}{n}\sum_{i=1}^{n} \exp\left(\frac{-x_i}{\beta}\right)\right)$$

$$x = -\beta ln(-ln(1 - \frac{1}{T}) + X_0 \tag{5}$$

This results in the Depth-Duration-Frequency curve for Vlissingen (figure D1). When divided by the duration the Intensity-Duration-Frequency curve (figure D2) is obtained.

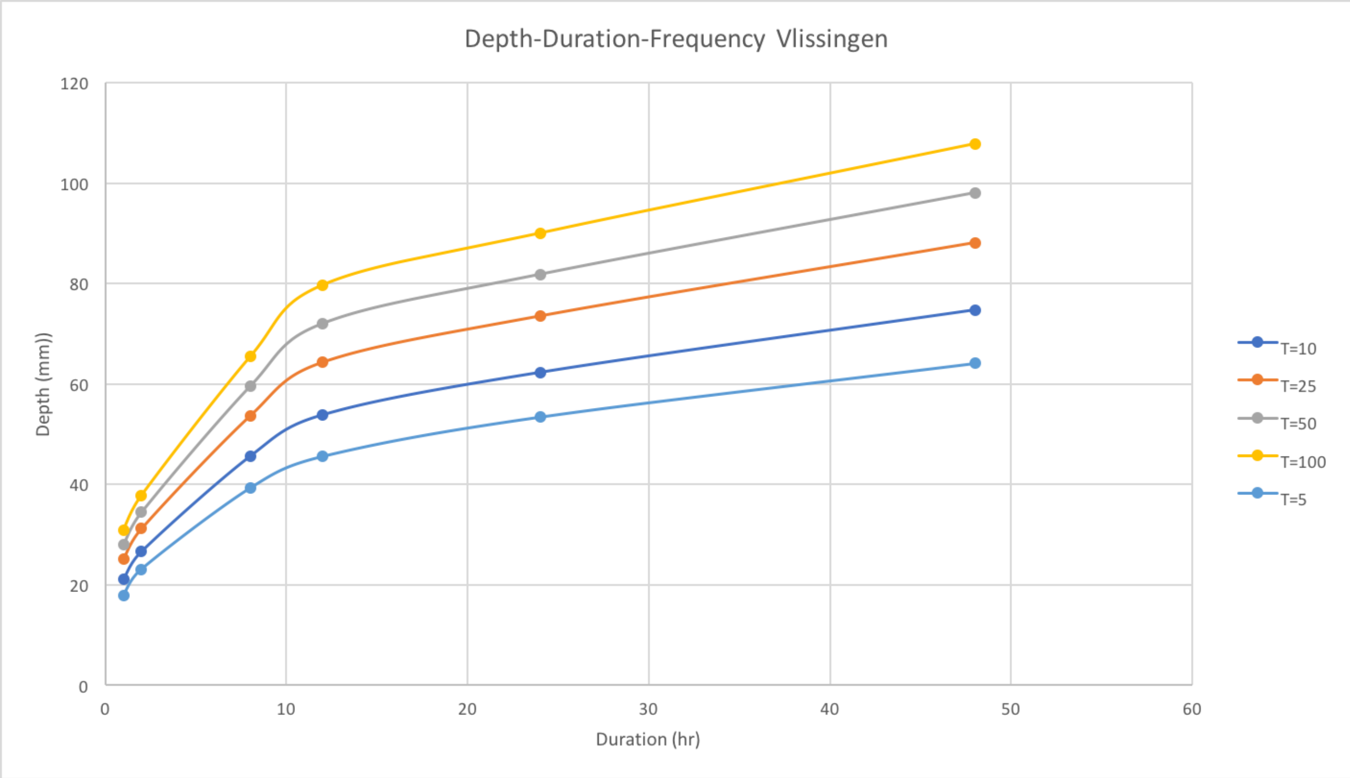


Figure D1. Depth-Duration-Frequency curve

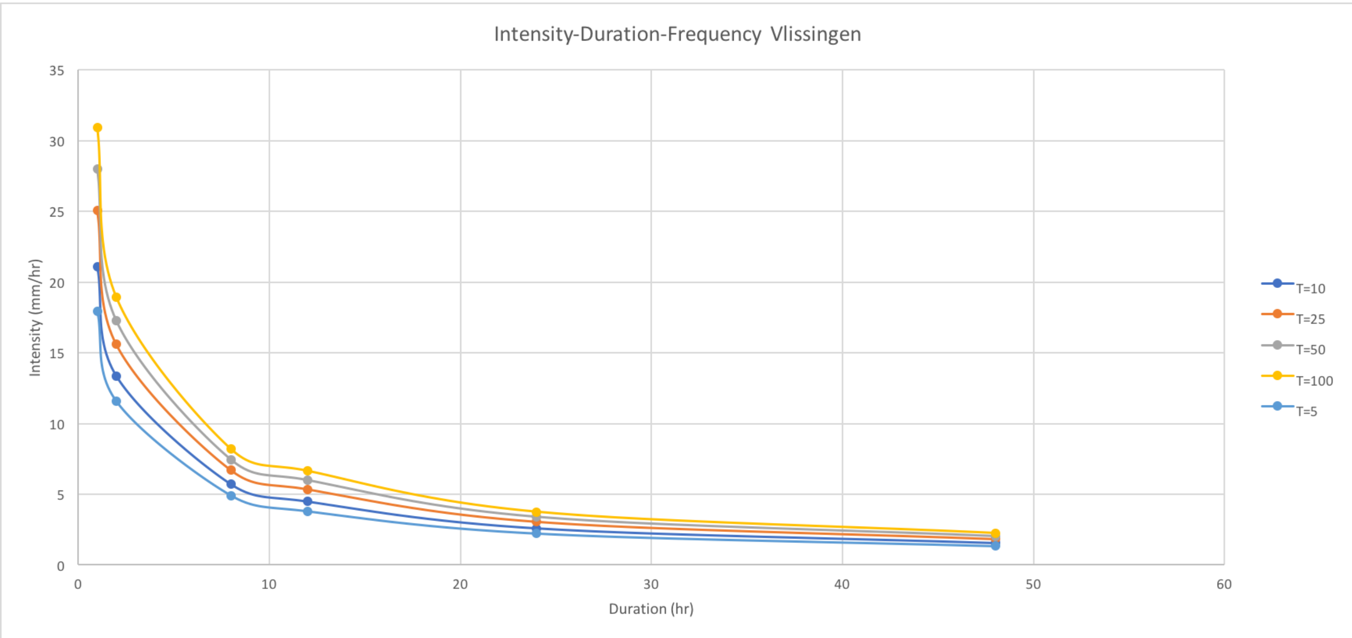


Figure D2. Intensity-Duration-Frequency curve

To transform the rainfall statistics into a more concise format to produce a design a storage-discharge-frequency curve is made with the same rainfall series as used for the DDF and IDF. This curve tells the amount of storage in cubic meters that is necessary per hectare under the conditions of a certain discharge capacity in the area.

Table D1
Land use properties

Land use	Share of total area	Impermeable area	Runoff coefficient
City Center	40%	75%	0.70
Sub-urban	40%	40%	0.45
Green area	20%	0%	0.20

A strongly simplified storage model has been set up. Based on the initial design from urbanism an coefficient of the total rainfall that will lead to runoff to the surface water is estimated. The following assumptions and estimated have been used: The total research area is 1081ha. Because of the simplicity of the model approach, only one runoff for the whole area can be used. To derive this average runoff for the area an indicative runoff calculation is made. The area is divided in three land uses with runoff coefficients (Van de Ven, 2016) as seen in table D1. Based on a storm of 60mm/h the volume of water that will run off is calculated and divided by the total rainfall. This leads to an average runoff in the area of 32,2% (runoff coefficient C=0.322). For the area the total volume of rainwater during a 24 hour period is calculated. If this volume exceeds the discharge capacity per day the remainder is considered to be stored in an infinite storage area. For each year the maximum needed storage capacity is determined. Similar to the construction of the DDF-curve an extreme value analysis is performed. This is repeated for several discharge capacities to construct the SDF-curve. This approach only includes fast stormwater discharge. The most important goal of the calculation is to act as a starting point for the needed storage capacities. In this project the effect on other disciplines and the study of interdisciplinary collaboration is of more importance. In a more detailed runoff calculation slow stormwater discharge is also considered including losses and retention. Including slow stormwater discharge will lead to a higher storage demand.

A typical discharge capacity of 12 mm/day will lead to a needed storage capacity of 225 m^3/ha once every 25 years. To convert the storage capacity into a spatial demand the maximum allowed increase in water level is set at 0.4m. The storage demand is divided by 0.4m leading to a needed area in square meters. This area corresponds with approximately 5.6% of the total area of Vlissingen. This requirement is given as feedback to the Urbanism design to incorporate the necessary amount of open water in the area.

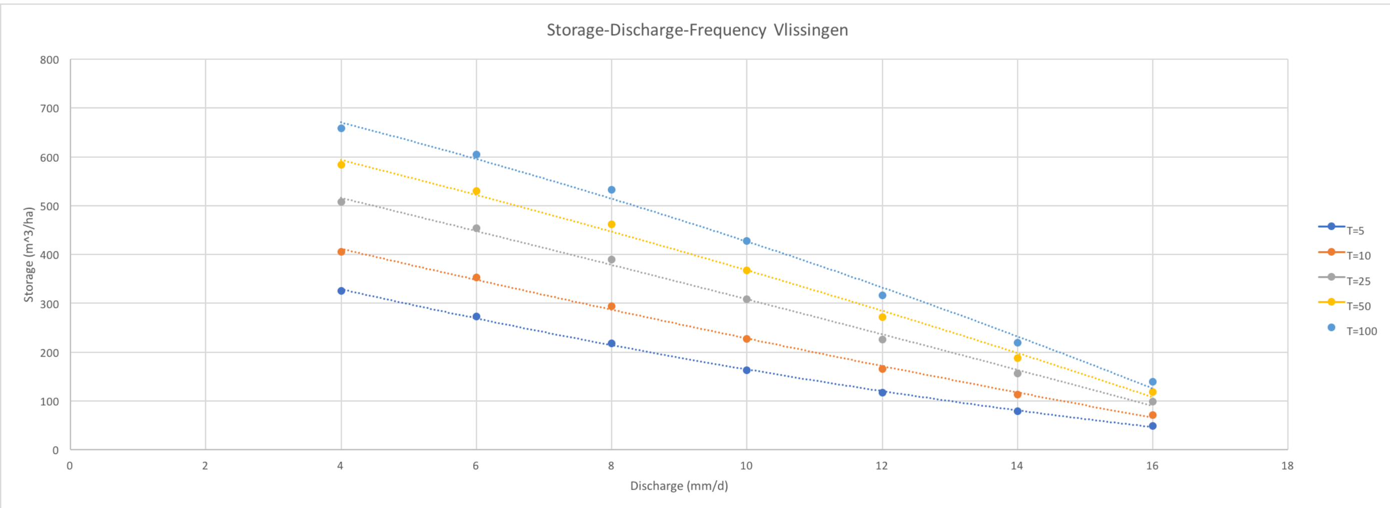
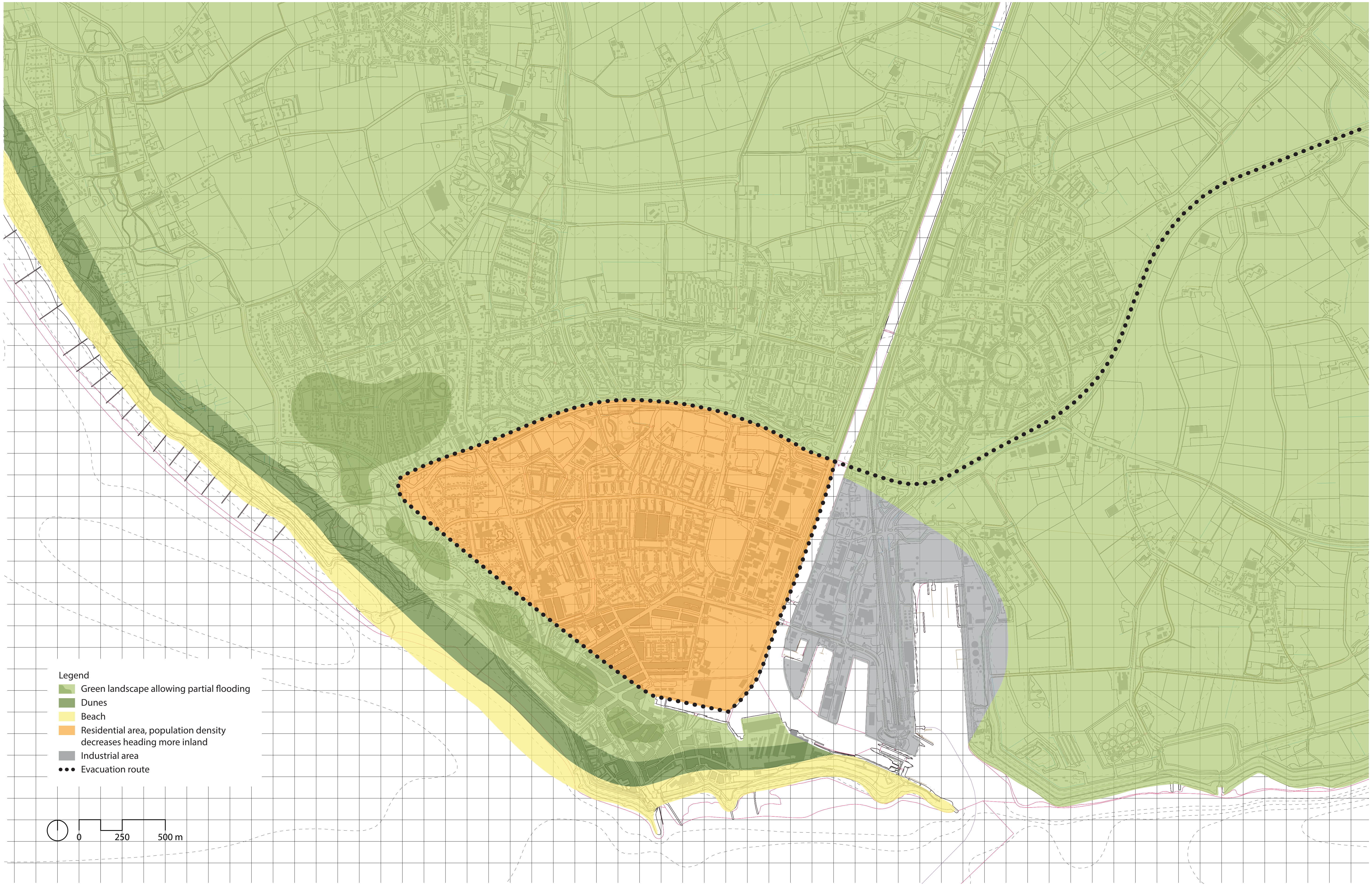


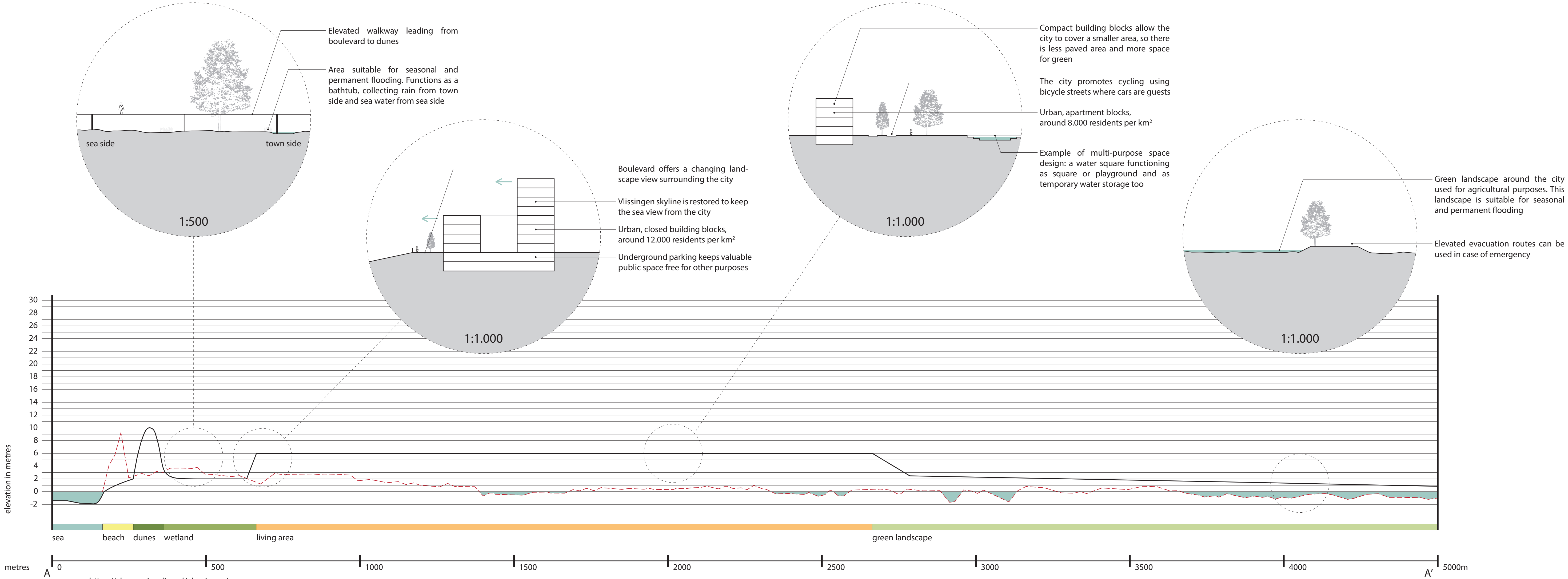
Figure D3. Storage-Discharge-Frequency curve

Appendix E
Urbanism

Appendix E1: Group A
Landuse plan



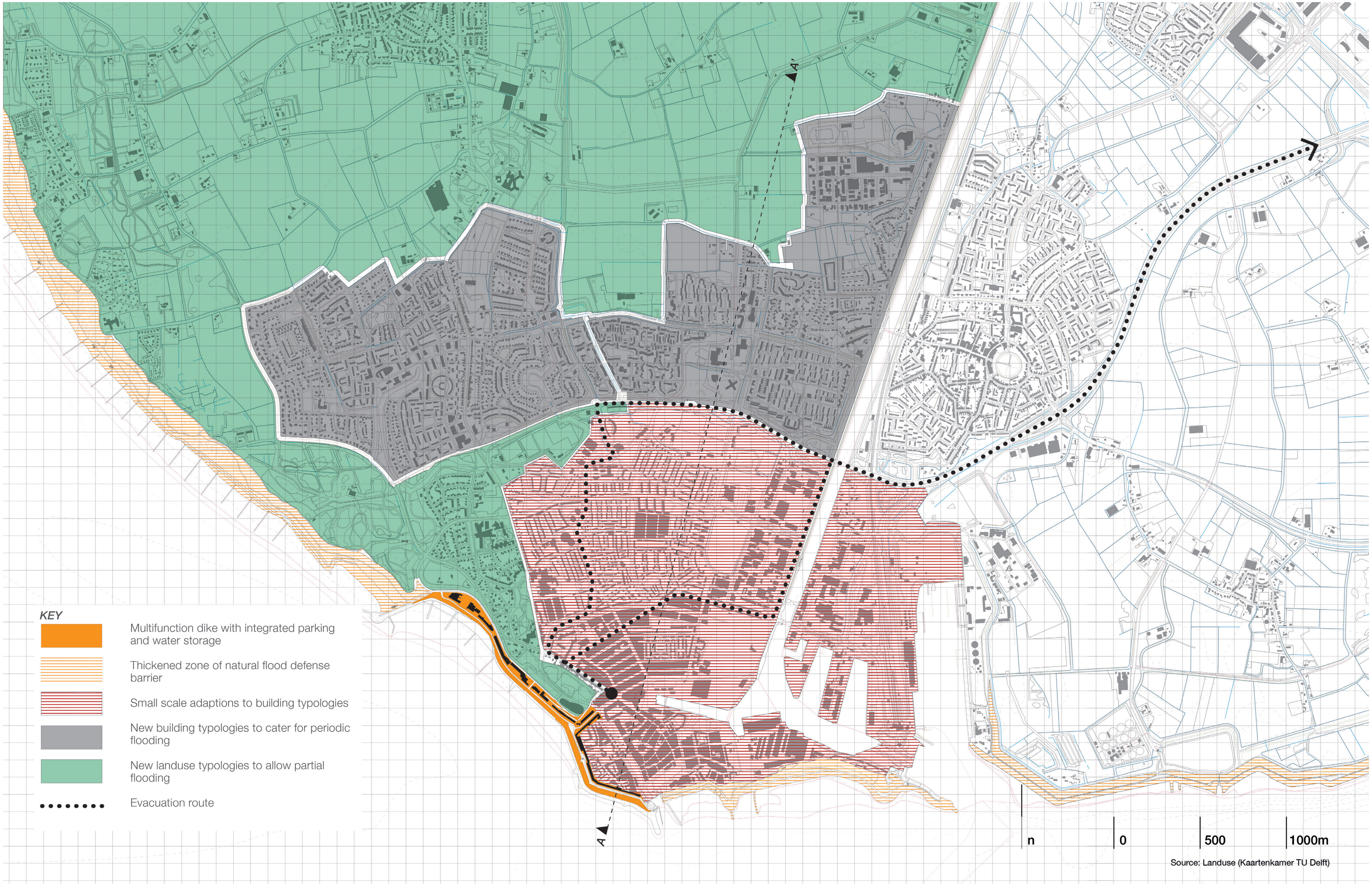
Section



source: https://ahn.arcgisonline.nl/ahnviewer/

Appendix E2: Group B

Landuse plan



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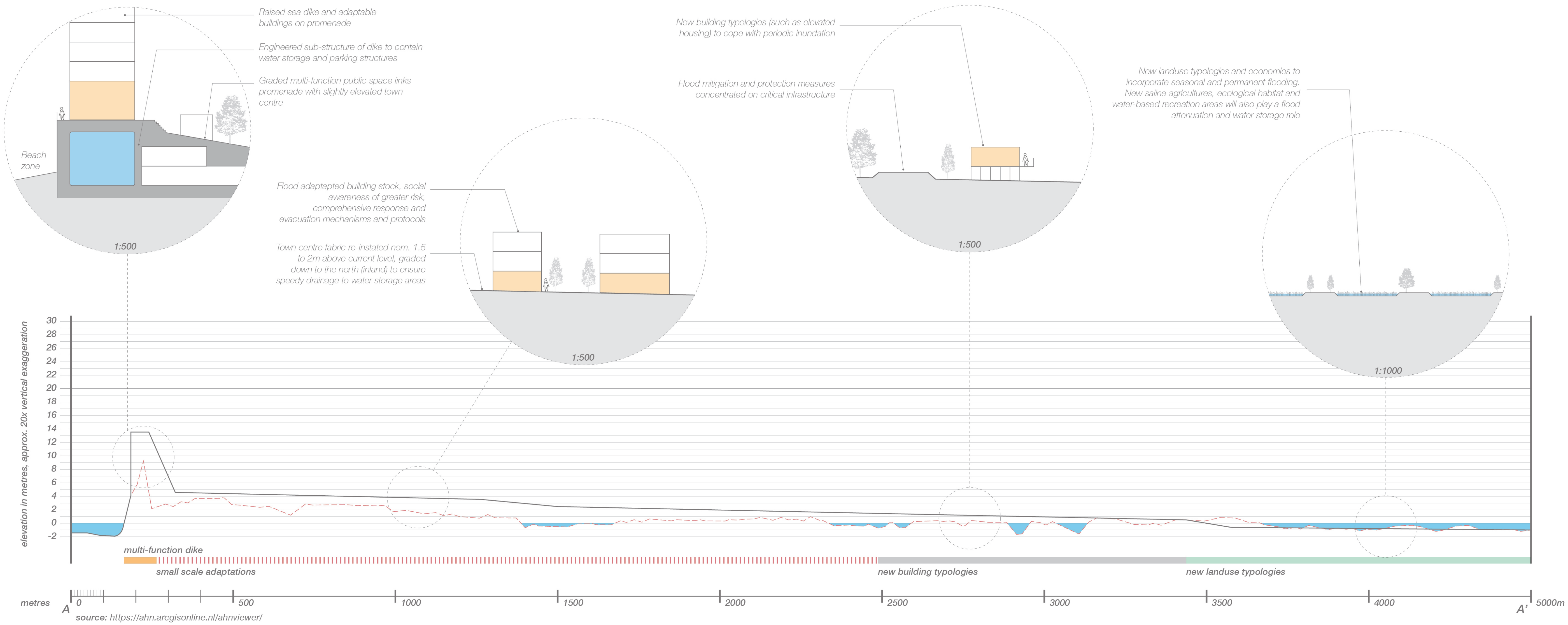
Raised sea dike and adaptable buildings on promenade
Engineered sub-structure of dike to contain water storage and parking structures
Graded multi-function public space links promenade with slightly elevated town centre
Beach zone
1:500
Flood adaptapted building stock, social awareness of greater risk, comprehensive response and evacuation mechanisms and protocols
Town centre fabric re-instated nom. 1.5 to 2m above current level, graded down to the north (inland) to ensure speedy drainage to water storage areas
1:500
New building typologies (such as elevated housing) to cope with periodic inundation
Flood mitigation and protection measures concentrated on critical infrastructure
1:500
New landuse typologies and economies to incorporate seasonal and permanent flooding. New saline agricultures, ecological habitat and water-based recreation areas will also play a flood attenuation and water storage role
1:1000
elevation in metres, approx. 20x vertical exaggeration
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
multi-function dike
small scale adaptations
new building typologies
new landuse typologies
metres
A
0
500
1000
1500
2000
2500
3000
3500
4000
A'
5000m
source: https://ahn.arcgisonline.nl/ahnviewer/