Enhancing the applicability of the polder concept

Thesis report
May 2012

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Title
Enhancing the applicability of the polder concept

Pages
67

Trefwoorden
Polder, reclamation, safety, sustainability, flexibility

Versie	Datum	Auteur	Paraaf	Review	Paraaf	Goedkeuring	Paraaf
	May. 2012	E. van der Pal		T.A. Nauta		N.C. van de Giesen	

State
Final

Preface

Dit onderzoek is voortgekomen uit de business case “Nieuw Polderland”, ingediend bij Topsector Water. Deze breed gesteunde businesscase was niet geselecteerd voor verdere uitwerking, maar Deltares heeft besloten er toch een vervolgstudie naar uit te voeren. Dit afstudeerrapport is het resultaat hiervan. De opdracht bestond uit het verkennen van de mogelijkheden om het polderconcept te verbeteren en te vermarkten in het buitenland. De vraag vanuit Deltares was gericht op drie belangrijke thema’s: veiligheid, duurzaamheid en flexibiliteit. Innovatieve oplossingen zouden de basis moeten vormen voor een verbetering van het concept. Ik heb in de uitwerking hierbij van verschillende bronnen gebruikgemaakt. Graag wil ik iedereen die mij heeft geholpen met het verzamelen en verwerken van de informatie bedanken voor de medewerking. In de eerste plaats mijn begeleiders vanuit Deltares, Sonja Karstens en Tjitte Nauta, en vanuit de TU Delft Nick van de Giesen, Olivier Hoes en Robert Verhaeghe. Daarnaast dank ik de deelnemers aan de brainstormsessie en alle andere specialisten waarmee ik in contact ben gekomen. En niet te vergeten, secretaresse Marcia de Jongh, bedankt voor alle logistieke hulp.

Summary

Delta areas are attractive areas for people to live in, and demand for space in delta areas is still increasing. However, since deltas are low-lying areas, they are vulnerable to flooding and have to cope with drainage problems. Polders provide opportunities for these developments, either by improving existing areas, or by establishing a new living environment. This research mainly focuses on urban polder development. It aims at finding solutions to the above-mentioned problems, by utilizing the polder concept. The problem that is elaborated in this research is defined as follows:

How can the polder concept be optimized to address lack of space issues and increase the safety levels in the delta areas of the world?

The main objective of this research is to explore the applicability of the polder concept in different global settings by finding (innovative) solutions to overcome the limitations of polders and thus improve the concept. In doing so, perspectives of government, business sector and knowledge institutes will be taken into account. The methods used in this research include a literature study, consultation of specialists, organization of a workshop and elaboration of the SWOT aspects.

To analyze the Strengths, Weaknesses, Opportunities and Threats of the polder concept a SWOT analysis was performed. Various parties (government, knowledge institutes, business sector) were invited, and via an interactive software system the participants were able to bring in the various SWOT aspects leading to the SWOT analysis. In this case, the strengths and weaknesses of the polder concept itself and the opportunities and threats of applying the polder concept have been analyzed. Table 1.1 gives an overview of the SWOT aspects and recommendations that were the result of the SWOT analysis.

Table 1.1 Summary SWOT analysis

External factors / **Internal factors**	**Opportunities for applying polders abroad** **O1** Profiling on the base of best practice **O2** Urbanization **O3** Climate change / development in flood risk areas **O4** Shortage of sand **O5** Applying the Netherlands' knowledge and expertise **O6** Financing research within the Netherlands	**Threats for applying polders abroad** **T1** Competition **T2** Bad governance / administrative weakness **T3** The negative image of polders abroad **T4** Discussion about safety **T5** Aspects concerning climate change
Strengths of polders **S1** Economic aspects **S2** Improve urban areas **S3** Use for various functions **S4** Contribute to increased safety **S5** Flexible layout possible **S6** Fresh water stocks	**How to make use of opportunities through strengths** **S1O2** Focus on poor urban areas to enhance the financial situation of these areas **S2O3** New spatial developments can be implemented in existing flood prone urban areas **S4O3** Flood risk areas can be made safer by applying the polder concept	**How to prevent threats through strengths** **S4T4** Create show cases to show that the concept improves safety to avoid the negative view about safety in polders **S5T5** The flexible concept allows for implementation of climate adaptation measures
Weaknesses of polders **W1** O&M requirements **W2** Safety / psychology **W3** Subsidence / seepage / sea level rise **W4** Maintenance costs **W5** Sustainability **W6** Lack of knowledge	**How to make use of opportunities to minimize weaknesses** **W4O4** Maintenance costs can be compensated by much lower construction costs compared to traditional reclamation **W6O5** Apply the Netherlands' knowledge and expertise to support other countries in their lack of knowledge about polder development	**How to minimize potential dangers where weaknesses meet threats** **W1T2** Develop an institutional and economic model with clear mandates / general means to address O&M **W2T3** Create safe polders in order to show that the negative image is not justified

The case studies that are described mainly show positive effects. From the case studies, it can be concluded that the best opportunities for polder development are to be found in urban areas. In dealing with climate change (e.g. more extreme rainfall), sea level rise and subsidence, existing urban areas can be protected by applying the polder concept. In addition, the polder concept can contribute to create new space needed to address the ongoing urbanization in delta areas.

Especially in developing countries the opportunities are quite promising. A concern, however, is the institutional aspect as the cooperation between the various parties proved to be very challenging. In the case of lack of resources, such as in Singapore, land reclamation through application of the polder concept might be the only option. When introducing polders in new areas the issue of addressing the psychological aspect of living below sea level remains a threat.

After having analyzed the SWOT aspects and the case studies, it was decided to focus the study on safety, sustainability and flexibility. The following sections describe the outcomes of these analysis.

Depending on the local setting (hydrological, geotechnical, spatial demands, etc.) various technical solutions may contribute to an increased safety level in polder settings. BioGrout and the application of climate dikes can be used to increase the strength of the given dike designs. Another technique that can be used to increase local safety levels is partitioning. The concept of partitioning is not new, but it can be combined with the polder concept. In this way, the polder concept can also contribute to the protection of important functions such as public utilities (power plants, hospitals, pumping stations, etc.).

Measures that lead to a more sustainable polder development are summarized as follows. Firstly, subsidence and seepage should be avoided as much as possible, either via law enforcement or via physical measures. Subsidence is related to the groundwater level, so high groundwater levels should be maintained. Seepage can be avoided by application of BioSealing, one aspect of the SmartSoils concept. Secondly, a principle as “Building with Nature” contributes to a more sustainable polder development as they take into account natural ecosystems and their services. This prevents the future polders to have negative effects on the surrounding area. In the third place, adverse water quality should be prevented. Although emission control is the best way to tackle the water quality problems, flushing the water system and applying helophyte filters or artificial wetlands may be applied to treat the contaminated surface water. In the fourth place, the ecological footprint of polders has to be minimized. This can be realized by minimizing the input of water by creating a fresh water lens below a part of the polder.

Flexible polder systems are able to cope with uncertainties and will have the capability to adapt to new, different, or changing requirements. In the field of engineering flexible design can be defined as designs that can adapt when external changes occur. The concept of flexibility can be incorporated in urban polder settings in various ways. Flexible housing development relates to dealing with population growth and changes in societal perspectives on build up areas. Flexible infrastructure relates to uncertainty in the effects of climate change. In urban polder settings, especially measures related to flooding have to be considered. Flexible infrastructure includes flexible dike design, flexible design of public areas and multiple uses of other facilities. Another example of flexible use of space is interim land use. Land can be used for a specific function that may be changed to another function depending on the future needs.

Recommendations for future polder design have been developed. First, a general design roadmap has been given. It consists of the conceptual design phase, in which a quick overview is created with financial, technical, environmental and operational implications and possibilities of the polder system in the local setting. In the detailed design, detailed specifications and requirements have to be defined. The detailed design also contains the detailed economic calculations. This leads to an overview of the economic benefits and the construction and O&M costs of the proposed polder. In addition, it takes into account the investment program including the various financing sources (loans and grants, governmental financing, private sector participation, local funds and community participation). An interesting remark on the economic considerations is that polders in almost all cases are economically beneficial, since construction costs are relatively low compared to future benefits. A cost-benefit calculation is in most cases made for a period of 25 to 30 years. The polder however, has a much longer expected lifetime, resulting in a distorted picture of the economic benefits on the long term. In the physical implementation phase the tender documents have to be composed, tendering takes place and construction of the various polder elements are included. The operation and maintenance phase consists of the future operation and maintenance of all water management components of the polder. In the monitoring and evaluation phase, information from the performance of the different water management components is collected and analyzed to present lessons learned and make adjustments when deemed necessary. In case of failure of specific elements, maintenance is to be scheduled.

In addition, the process of physical implementation has been developed for an existing urban area that is prone to flooding. The most important step in the implementation of the polder is the setup of an institutional body that is responsible for maintenance and fundraising. The second step is to realize local ownership. People get a sense of self-esteem when paying taxes, resulting in investments in their living environment. Then, the facilities have to be provided or improved. Especially drinking water supply is a very important aspect of the physical implementation phase, related to subsidence problems. As a last step, infrastructure needs to be created. Most important aspects are the dikes, drainage and storage facilities and pumping stations.

Conclusions drawn from the research can be summarized as follows:

- Safety in future polder developments seems to receive more attention than sustainability and flexibility. The challenge however is to construct a polder in such a way that it is as sustainable and flexible as possible.
- In order to identify new business opportunities for the Dutch water sector the focus should be on urban polder development. The reason for that is that most economic potential is to be found in these urban delta areas.
- In general, two types of urban polder development can take place. Draining lakes or parts of the seabed and thus creating new land, or protecting existing land against flooding by making local compartments. The second application seems to have greatest business potential in the future. Urban areas that are at or near sea level are even more prone to flooding due to sea level rise and ongoing subsidence. These areas profit from applying the polder concept in order to prevent to be flooded permanently.
- The conclusion drawn from the literature study and case studies is that polders have been developed with various degrees of success. The most important reasons for the cases that were not implemented are a limiting institutional setting and the lack of financial resources. The institutional shortcoming relates to the fact that polders require a long-term commitment for operation and maintenance. If the institutional setting is not able to support this and support will only last for the political term of the initiators, polder development will not sustain.
- It became clear that three factors are of high importance to the success of polder development. The most important aspect is the institutional setting. Related to the construction and operation and maintenance, sufficient financial resources should be

available in order to let the polder sustain. In addition, the availability of resources is an important factor. In case of sufficient availability of filling material, heightening of the area might be the preferred option from an economic and sustainable point of view. Besides these three, however, other factors may also be important, such as technical know how, local experience with water management and socio-cultural aspects.

- Polders are in almost all cases economically beneficial and highly competitative compared with traditional land reclamation, since construction costs are relatively low compared to future benefits and filling material often quite costly. A cost benefit calculation is in most cases made for a period of 25 to 30 years. The polder however, has a much longer expected lifetime, resulting in a distorted picture of the economic benefits on the long term.
- Safety problems may be solved in various ways, such as the application of the climate dike concept and applying various methods for stormwater storage. An interesting development that may lead to an increase of safety levels by using the polder concept is the protection of utility facilities. By creating polders around utilities, local safety increases. In case of high water levels, this concept would prevent disruption of society as basic utilities will remain available during flood periods.
- Sustainable polder development may be implemented in future polders by applying a concept such as “Building with Nature”. Important aspects that have to be tackled are seepage and subsidence. Especially subsidence caused by drinking water abstraction is a problem.
- Surface water quality within polders can be managed by application of artificial wetlands and flushing the polder by fresh water from outside the polder. Saline water systems may also be considered,. During the research, it was not found that in urban water systems high salt concentrations are a major constraint.
- An advantage of the polder concept as related to flexibility is the extensibility of polders. Flexible options for financing the complete polder may be available, by dividing the construction into different phases.
- Flexibility may also be introduced by considering interim land use. An area gets a tempral function fulfilling the needs on the short to medium term, but on the long term it remains available for (often unsure) other functions.
- Constructing polders in dense urban delta’s will lead to various business opportunities for the three sectors (knowledge institutes, business sector, government) within the Netherlands. Knowledge institutes may contribute to conceptual design studies and carry out innovative research into e.g. sustainability and climate proof building. The business sector may profit by the technical implementation of the polders. In addition, Dutch engineering firms may carry out the detailed design. Governmental institutions may show their excellent experience with organizing the operation and maintenance in polder settings and by giving support to institutional and organizational aspects.

Recommendations have been divided into recommendations for further research and recommendations for future business developments. Recommendations for further research may be summarized as follows.

- A detailed study into the optimal institutional settings of urban polders in order to get more insight into which settings are suitable and which are not. An institutional model may be developed in which the requirements for successful polder development are taken into account.
- Another limiting factor that came up during the research is the financial capacity of the local setting. Further research into this topic may provide a better insight into the global

settings that are suitable for polder development. It may be considered to include the financial aspects in the above-mentioned institutional model.

- A solution to water quality problems that has been addressed is the application of saline water in urban polders. Further research into the effects on the urban environment is required.
- Another topic that needs further investigation is the development of a fresh water lens below the polder. It is believed that applying a fresh water lens below (a part of) the polder contributes to an increase of water availability for multiple functions, reduces the subsidence and prevents salinity intrusion.

The recommendations for future business development may be summarized as follows:

- A recommendation that comes forward from the research is to promote the polder concept in existing urban areas. It is attractive from a business point of view, especially in areas that face safety problems. New polders are also applicable for developed countries with a lack of fill material.
- Possibilities for future business development for knowledge institutes relates to the application of Dutch innovations such as the “Building with Nature” concept. Other specialties of the Dutch knowledge institutes that may be applied in future polder projects relate to the improved dike design, optimal water system design and soil settlement analysis studies.
- A recommendation to an increase of the involvement of the business sector relates to the subsidence caused by uncontrolled abstraction of groundwater. The Dutch drinking water and the drinking water distribution system have some of the highest standards in the world. The experience built up may be used in those areas that require a new or renovated drinking water system in combination with a polder system.
- Governmental institutions, such as water boards and municipalities, can be involved in the polder development process by assisting in the set up of an administrative body. The Dutch governmental institutions can also demonstrate their excellent experience with organizing the operation and maintenance in polder settings.

Content

Appendices

1 Introduction

1.1 Problem definition

Deltas are usually areas with major economic potential because of their strategic location close to seas and inland waterways. Deltas provide also some of the world's most fertile lands important for food production. That is why navigation and port development, oil production and refinery as well as agriculture and fisheries have always been important for the economic development of deltas. Attracted by these potentials, large numbers of people live in deltas; a development which has led to the growth of coastal (mega-) cities. Demand for space in delta areas is still increasing. However, since deltas are low-lying areas, they are vulnerable to flooding and have to cope with stagnating drainage (Van der Most et al., 2009).

Polders provide opportunities for these developments, either by improving existing areas, or by establishing a new living environment. Originally, polders were mainly reclaimed for agricultural purposes. Since the last decades however, polder projects are also implemented for other development, such as urban development, nature development, recreation, or for safety reasons. Developing polders may also involve development or improvement of infrastructure, development or improvement of a water management system, the provision of public facilities (such as schools, hospitals, shopping centers), development of industrial areas and installation of housing provisions (such as water and electricity supply, sewerage and communication lines). Considering the above-mentioned recent developments in delta areas, this research mainly focuses on urban polder development.

The definition of a polder used in this research study is described below. It is extracted from the study "Polders of the World", which was prepared in 1982 (Segeren et al, 1982).

> *A polder is defined as a level area which has originally been subject, permanently or seasonally, to a high water level (groundwater or surface water) and is separated from the surrounding hydrological regime to be able to control the water levels in the polder (groundwater and surface water).*

This research aims at finding solutions to the above-mentioned problems, by utilizing the polder concept. The problem that is elaborated in this research is defined as follows:

> *How can the polder concept be optimized to address lack of space issues and increase the safety levels in the delta areas of the world?*

1.2 Objective

The main objective of this research is to explore the applicability of the polder concept in different global settings by finding (innovative) solutions to overcome the limitations of polders and thus improve the concept. In doing so, perspectives of government, business sector and knowledge institutes will be taken into account.

1.3 Research questions

The following four research questions are addressed to achieve the objective of the research.

1. ***Where are polders currently found and how successful are the implementations?***
   The outcome is a global overview of the locations of the current polders to show the successes of polder development in the past.

2. ***What are recent experiences and prospects of applying the polder concept?***
   Several case studies are analyzed. Goals and challenges are taken into account, as well as the institutional setting. Cases are compared, based on three important aspects: safety, sustainability and flexibility. To conclude, an overview of possible improvements is given, based on learning experiences in the different case studies and additional literature review.

3. ***What are the Strengths, Weaknesses, Opportunities and Threats (SWOT) of polders?***
   The goal of this question is to explore how the limitations of polders can be eliminated or minimized and how its strengths can be emphasized. Moreover, this research also attempts to identify opportunities for implementation of the polder concept and at the same time become aware of possible threats.

4. ***How can the concept of polders be improved given different global settings and what are opportunities for The Netherlands?***
   Recommendations for future polder developments are given. Firstly, design considerations that are applicable for the polder concept in general are given. Then, design and process recommendations for polders in different global settings are elaborated. Finally, the opportunities for the Netherlands to utilize the polder concept abroad are considered.

1.4 Methodology

The methods used in this research conduct of a literature study, consultation of specialists, organization of a workshop and elaboration of the SWOT aspects. The literature study consists of an analysis of general data about polders, followed by a selection of case studies worked out in detail. In order to obtain the information specialists having knowledge and experience in the field of polder development were interviewed. In the second place, international literature was reviewed. The next aspect in the research is the SWOT analysis. The method used for collecting the various SWOT aspects was the organization of a brainstorm session. Various parties (government, knowledge institutes, business sector) were invited, and via an interactive software system the participants were able to bring in the various aspects of the SWOT analysis. After the aspects were collected, they were discussed amongst the participants.

The results of the brainstorm session have been described in this report, leading to a SWOT matrix with recommendations for applying the polder concept abroad. The analyses of the case studies and SWOT aspects have led to design considerations for urban polders. The general design principles that were considered are safety, sustainability and flexibility. After having defined these principles, a problem and solution tree of each of them is given and possible ways to enhance the aspects related to the polder concept have been elaborated.

Next, a design roadmap has been developed. Finally, economic aspects and perspectives for the Netherlands to apply polders abroad have been taken into account.

1.5 Layout of the report

This report has been structured in the following way. In Chapter 2, the SWOT analysis is elaborated. In Chapter 3, currently existing polders and polder projects have been analyzed. This is done by looking into polder developments in general, followed by an elaboration of selected case studies. In Chapter 4, design aspects for urban polders have been analyzed and recommendations for future polder design are given. Chapter 5 presents the conclusions and elaborates to what extent the research questions are answered. Chapter 6 gives recommendations for future research.

2 Strengths, weaknesses, opportunities and threats of polders

2.1 Method

To analyze the Strengths, Weaknesses, Opportunities and Threats of the polder concept a SWOT analysis was performed. In this case, the strengths and weaknesses of the polder concept itself and the opportunities and threats of applying the polder concept have been analyzed.

The method used for gathering the SWOT aspects is a brainstorm session. People from different institutions in the field of water management (DHV, Deltares, Witteveen+Bos, Royal Haskoning, Arcadis, Grontmij, TU Delft, Unesco-IHE, Water Governance Centre, KWR) and having knowledge about polders were invited. In Appendix A a list of people from participating companies is attached. The software used for facilitating the brainstorm session is developed by Groupsystems.[1] This software is designed to work out ideas on a specific subject by several participants. The brainstorm session was held on 25 October 2011 in the Deltares Electronic Board Room. The participants all had access to a laptop computer with the software installed on it. The software enabled the participants to type in the ideas, which then appear immediately on the screens of the other participants. In this way, in a relatively short period of time over 200 SWOT-aspects were collected. Obviously, many of the ideas mentioned were more or less similar and could be eliminated or clustered. The results of the clustering and prioritizations of ideas are depicted in this chapter. Finally, a SWOT matrix is made to develop recommendations for future polder development.

2.2 Strengths of the polder concept

The strengths of the polder concept are clustered as follows:

Economic aspects
Under specific conditions and dependent on the size of the new land polder development is cheaper than the more conventional ways of reclaiming land. This usually relates to the costs of the required fill material and its availability. Besides, polders may be developed in different phases. Costs of the complete project will be spread over time in this way.

Improve/expand urban areas
When applying the polder concept in existing urban areas, new spatial developments or required compartment dikes are relatively easy to fit in. Moreover, minimal resources are required to realize such developments.

Polders can be used for various functions
Within polders combinations of different functions can be realized. An example is the use of internal water storage reservations for nature development and/or recreation. In addition,

1. *http://www.groupsystems.com/index.php*

potentially risky functions or activities can be better controlled by placing them in compartments. In this way, the existing land can be protected against possible calamities.

Polders can contribute to increase the safety level
Existing areas that are getting less safe due to the combination of land subsidence and sea level rise can get a higher safety level by applying the polder concept. In addition, by applying compartments, local safety becomes more controllable and safety levels can be locally adapted to the functional use within the compartments.

The water management and layout can be organized exactly as desired
The water system in a polder can easily be managed and different lay-outs and internal water quality management schemes can be applied. The layout and design can be focused on present and future functions. This also implies that a flexible approach is possible with regard to future uncertainties.

Fresh water stocks
New fresh water stocks can be created by collecting rainwater in the polder. The so-called internal reservoirs offer options for use for different functions, such as drinking water supply or floodwater storage during extreme precipitation events.

2.3 Weaknesses of the polder concept

The weaknesses of the polder concept are clustered as follows:

Operation and maintenance (O&M) requirements
Polders require careful operation and maintenance. For this, a capable organization is required. Inadequate maintenance and operational management can lead to dangerous situations.

Another aspect of operation and maintenance is that many different parties need to participate and cooperate. In many countries institutional weakness, inefficient governance and insufficient financing arrangements for operation and maintenance is often the case.

Safety issue
The risk for flooding in polders is considered relatively high requiring ample attention to prevent dike failures, sufficient storage / pump capacity and flood adaptation measures. In addition, the psychological feeling of unsafety may result in less attractive living environments.

Subsidence, seepage and sea level rise
Due to pumping land subsidence may occur. As a result, safety is further affected (due to increased inundation depths when flooded), more pumping capacity is required and more seepage is to be expected.

When applying polders in sea coastal environment, saline seepage can take place, possibly affecting existing functions (agriculture, nature, local reservoirs for drinking water , etc.),

Costs
Pumping will be an important cost factor and may even go up in future due to subsidence and sea level rise. In addition, operation and maintenance are significant cost factors. Another

aspect related to costs relates to required water storage. For instance in tropical areas with heavy rainfall more storage is required. For storage, significant costly space is required that cannot be used for other functions. Moreover, required phasing in construction works is often complex and time-consuming which is financially unfavorable.

Sustainability
Constant pumping requirements and therefore energy consumption make the concept of polders not very sustainable.

Loss of nature and other functions
During the SWOT exercise, it was believed that polders might be less attractive from a biodiversity point of view. Moreover, polders may have an impact on the internal and external environment (release of freshwater in a saline environment, water quality and mosquito problems caused by the typical polder water systems, etc.). However, polders may also offer opportunities to support attractive ecosystems (wetlands) through water quantity management, and control adverse water quality conditions to occur by applying constant flushing.

Insufficient knowledge concerning polder development
In many countries, insufficient knowledge is available concerning development of polders. For example, the building of dikes and other elements is very critical and asks for good engineering practices and careful operation and maintenance.

2.4 Opportunities for applying polders abroad

The opportunities of the polder concept are clustered as follows:

Profiling on the base of best practice / competition on the world market
An opportunity for the Netherlands is developing showcases to demonstrate the unique feasibility of the Dutch polder concept. The Netherlands is known for its excellent knowledge on land development following to the polder concept. In addition, the Dutch Water board set-up proved to be an excellent institutional model to deal with operational water management aspects such as safety and water quantity and quality management.

Urban area (external trend)
Ongoing urbanization and pressure on the delta regions offer many opportunities for development of new polders, as well as using the polder concept for protecting existing urban areas (see below). Since the costs of land in these areas is very high, creating a polder is profitable in many situations.

Climate change / development of flood risk areas (external trend)
The current attention to issues as climate change offer opportunities for polder development. Land that is just above sea level may drop to below sea level in the future. For these areas polder developments may offer adequate solutions.

Shortage of sand
Polder development offers opportunities in areas in where resources such as sand (or other fill material) are too costly or lacking.

Applying the Netherlands knowledge and expertise
The Netherlands can fulfill a role in the design, construction, and possibly management of polders. Sustainable approaches may work out best (e.g. applying the Building with Nature concepts). In many countries, there is insufficient knowledge about polder development and maintenance. The Netherlands can demonstrate many successful examples of polders.

Financing research within the Netherlands
With new polder developments, new knowledge and research within the Netherlands can be strengthened and partly financed by money generated from activities abroad.

2.5 Threats for applying polders abroad

The threats of the polder concept are clustered as follows:

Competition
Dutch knowledge and labor is considered very expensive and the strategic advantage the Dutch players have over others within the **competitive** land development business is declining.

Bad governance / administrative weakness
Adequate operation and maintenance as found in the Netherlands appears difficult to realize elsewhere. A threat for polder development in some countries relates to the local institutional setting and cultural and/or religious issues (corruption, woman labor, taxation, etc.). Polder development requires a long term support (like operation and maintenance, stable governance, etc.). In many politically instable or less democratic countries it is questionable whether polder development should be pursued.

Limited investment possibilities
In relation to the current global economic crisis, there are less opportunities for polder development, which in turn may lead to less interest to become involved in the polder development business.

The negative image of polders abroad
In the Netherlands and some other countries land is given back to the sea. This gives a negative signal to the outside world. In addition, recent (almost) flood events in Dutch polder settings are not very helpful in selling the polder concept.

Discussion about safety
Experiences with floods due to overtopping or dike breaches lead to a discussion on safety. In addition, the larger vulnerability to earthquakes, terrorist attacks and other possible failures compared to other ways of land reclamation contributes to a negative view concerning safety in polders.

All aspects concerning climate change
More extreme monsoon rains, occurrence of drought and sea level rise are threats for using the polder concept. In particular, in delta areas the requirement for sufficient dewatering capacity exists. Already in the design phase, future water surpluses and deficits should be taken into account. The level of climate change is uncertain, and therefore also how to cope with it.

2.6 SWOT-matrix

The SWOT matrix gives an overview of the possibilities of utilizing the polder concept. It combines the aspects of the SWOT to come to recommendations for the future.

Table 2.1 SWOT matrix

External factors **Internal factors**	**Opportunities for applying polders abroad** **O1** Profiling on the base of best practice **O2** Urbanization **O3** Climate change / development in flood risk areas **O4** Shortage of sand **O5** Applying the Netherlands' knowledge and expertise **O6** Financing research within the Netherlands	**Threats for applying polders abroad** **T1** Competition **T2** Bad governance / administrative weakness **T3** The negative image of polders abroad **T4** Discussion about safety **T5** Aspects concerning climate change
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Weaknesses of polders **W1** O&M requirements **W2** Safety / psychology **W3** Subsidence / seepage / sea level rise **W4** Maintenance costs **W5** Sustainability **W6** Lack of knowledge	**How to make use of opportunities to minimize weaknesses** **W4O4** Maintenance costs can be compensated by much lower construction costs compared to traditional reclamation **W6O5** Apply the Netherlands' knowledge and expertise to support other countries in their lack of knowledge about polder development	**How to minimize potential dangers where weaknesses meet threats** **W1T2** Develop an institutional and economic model with clear mandates / general means to address O&M **W2T3** Create safe polders in order to show that the negative image is not justified

Summarizing, the following recommendations are obtained from the SWOT exercise:

- Focus on poor urban areas to enhance the financial situation of these areas
- New spatial developments can be implemented in existing flood prone urban areas
- Flood risk areas can be made safer by applying the polder concept
- Maintenance costs can be compensated by much lower construction costs compared to traditional reclamation
- Apply the Netherlands' knowledge and expertise to support other countries in their lack of knowledge about polder development
- Create show cases to show that the concept improves safety to avoid the negative view about safety in polders
- Develop an institutional and economic model with clear mandates / general means to address O&M
- Create safe polders in order to show that the negative image is not justified

2.7 Conclusions

From the SWOT analysis, it can be concluded that the focus in terms of business perspectives should be on urban polder development. Especially areas that need flood protection are considered to be suitable, since these areas will disappear if no action will be taken. In areas in which the land prices are very high, polder development provides ample business opportunities.

From the SWOT analysis, three issues appeared to be of special interest. In the first place, special attention needs to be paid to safety. Due to the possible severe consequences of floods in polders, safety levels should be high. In the second place, sustainability is to be considered. Factors as subsidence, seepage, sea level rise and pumping water out of the polder are not considered sustainable and should therefore be mitigated or compensated. In addition, negative impacts on the adjacent area should be avoided. In the third place, flexibility is a point of interest. Future changes such as climate change and population increase should be accommodated by and already be incorporated in the design. In the Chapter 4, these issues will be elaborated in more detail.

3 Existing polders and polder developments

3.1 Introduction

The goal of this chapter is to give an answer to the first two research questions. In order to do so, an overview has been given of the total reclaimed area in a number of countries, largely addressed through the polder concept. A timeline of polder development has been given to illustrate the long history of the polder development process. Hereafter, polder development in The Netherlands is compared to polder development in Japan, to show the similarities and to show how successful polder development can be. Next five case studies have been worked out in more detail. The main aspects that are considered are safety, sustainability and flexibility. To conclude this chapter, conclusions and answers to the first two research questions have been given.

3.2 Polder developments around the world

In this section, international polder developments are presented (see Table 3.1). The table shows that the polder concept was applied extensively in the past, but in recent years attention has shifted to other reclamation methods despite the fact that the polder concept has proven to be very valuable in the past. As Vrijling (2008) states, it is very well possible to live in polders when the dikes are maintained properly.

Table 3.1 shows the countries in which polder development has taken place (Miura et al., 1994). The list is not complete; as for several countries no information is available. In addition, the data is based on an analysis performed in 1982. In the years after there have been some new polder developments and some other polders have been inundated. Unfortunately, it proved to be rather difficult to collect data about these developments. However, the list gives a first impression of the most important polder developments in the world.

Table 3.1 List of polders developments in the world

Country	Estimated area (x1000ha)	Country	Estimated area (x1000ha)
Africa			
Egypt	1800	Cuba	150
Chad	15	Jamaica	10
Ghana	25	Trinidad & Tobago	13
Guinea-Bissau	400	Canada	120
Kenya	118	United states	88000
Madagascar	30	Argentina	3500
Morocco	43	Brazil	5500
Mozambique	28	French Guyana	100
Nigeria	100	Surinam	45
Rwanda	10	Venezuela	120
Senegal	500		
Somalia	10	**Europe**	
Sudan	200		
Zambia	520	Bulgaria	75

		C.I.S.	1400
Asia and Oceania		Denmark	50
		Germany	450
Australia	10	France	400
Bangladesh	8500	Great Britain	100
Burma	650	Greece	45
Cambodia	40	Hungary	300
China	5600	Irish Republic	10
India	4400	Italy	1250
Indonesia	43000	Netherlands	715
Japan	2600	Poland	171
Korea	1600	Portugal	28
Malaysia	420	Romania	30
Pakistan	30	Slovakia	500
Sri Lanka	70	Spain	150
Taiwan	48	Yugoslavia	65
Thailand	85		
Turkey	50		
Vietnam	1100		

3.3 History of polder development in the Netherlands

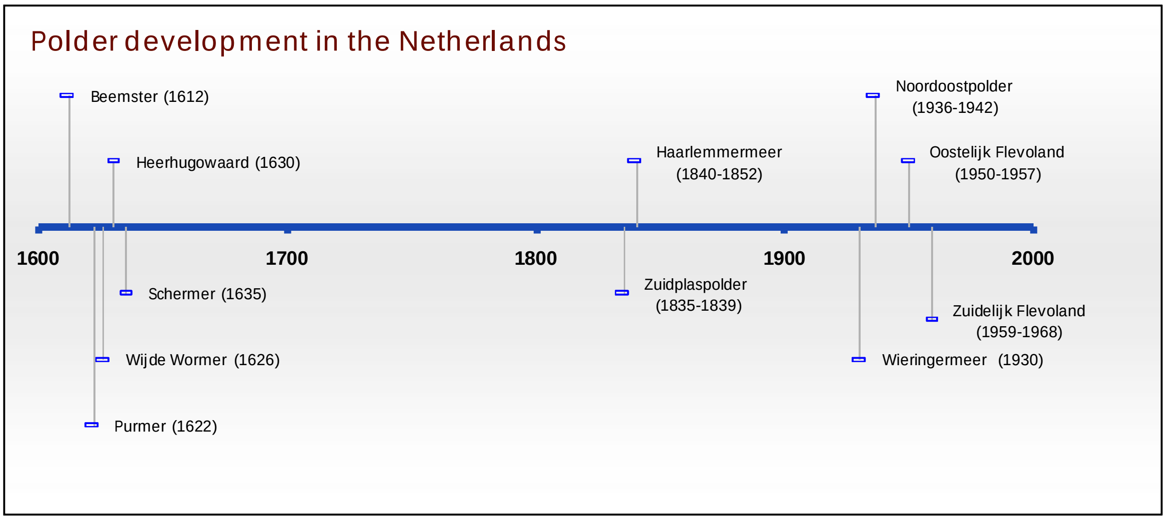


Figure 3.1 Time line of the most important polder developments in the Netherlands (Van der Ham, 2009).

In 1608, the preparations for reclaiming the Beemster (7100 ha) were started. A dike was build, a circular ditch was dug and construction of 21 windmills was started. One year later the polder appeared to be dry, but due to a heavy storm in 1610 the dike collapsed. 20 km of dike was destroyed. The construction started again and in 1612 the polder was pumped dry again. The costs of the project were much higher than earlier anticipated. The reasons for this were the need of much more windmills than expected and the unforeseen additional capacity of the water system that was required. The construction of the Purmer polder (2750 ha) was developed more smoothly. After two years of pumping the polder, with a depth of three to five meters, was dry. The construction period of the Wijde Wormer (1620 ha) was even shorter.

Within two years the polder was dry even though the ring dike breached two times. The following large polder was the Heerhugowaard (3527 ha). Before polder construction it was a lake with many small islands. After about five years of construction the polder was dry. The Schermer polder (4770 ha) was constructed using a new technique. The water was discharged in four different steps. The mills were distributed at different locations in the polder and discharged to ditches. Then, a next group of mills pumped the water into another ditch, followed by two similar steps. In 1635 allotment of the new land was started.

As can be seen in Figure 3.1, no large polder projects were developed between 1650 and 1830. Polder development appeared not attractive during that time as the polders developed so far were having problems with drainage. The investments for private parties were therefore unsure and therefore too risky. Hence, polders such as the Haarlemmermeer (18100 ha) and Zuidplaspolder (4355 ha) were financed by the state. The Haarlemmermeer was at that time by far the largest polder constructed. Problems that arose related to the occurrence of diseases and a lack of proper management leading to unpleasant living conditions.

In the twentieth century the Zuiderzee polders were constructed. In section 2.5.1. these polders will be described.

The most important stimulus to polder development in the Netherlands was the associated increase of safety against flooding of the existing land. Other reasons to create the new polders related to the desired extension of agricultural land and increase of employment. The new land proved to be very valuable in later years.

3.4 Selected case studies

In this chapter, some polder developments are described in more detail. The cases described have in common that Dutch parties were involved during their development and/or construction. The large Dutch polder constructions is elaborated to show how successful polder development was in the Netherlands. In addition, the experience gained during the past few hundred years is very valuable for polder development in other global settings. The case studies selected are in different phases of the project cycle to show which problems can occur during these different phases. The elaborated projects have varying degrees of success, which provides an overview of learning experiences.

In this chapter, the following polder developments are described in detail:

- IJsselmeer polders, the Netherlands (maintenance phase)
- Polder development in Laguna de Bay, Philippines (development phase)
- Land reclamation in Singapore (development phase)
- The Semarang polder, Indonesia (construction phase)
- Polder development in Louisiana, USA (construction phase)

The cases in Indonesia and the USA have in common that they are constructed in order to protect existing urban area. The other polder projects are new land reclaimed from sea or lakes. The cases in the Philippines and Singapore are still in the conceptual design stage at the moment.

3.4.1 IJsselmeer polders, the Netherlands

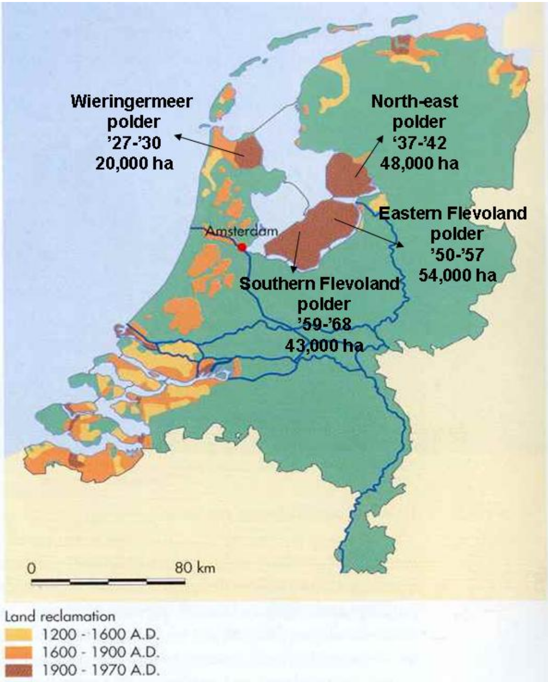


Figure 3.2 Map showing the IJsselmeer polders

Introduction

The Dutch climate is characterized by an annual rainfall of over 750 mm distributed evenly throughout the year. Evaporation, however, is strongly seasonal. It is low in winter resulting in a considerable rainfall surplus. In summer, the evaporation exceeds the rainfall. The net result per annum is a rainfall surplus. This means that in the Netherlands, the land can be used continuously when the rainfall surplus can be drained naturally or else be discharged into the sea by artificial means. An estimated 40% of the country's land area could not be utilized without artificial drainage (Segeren et al., 1982).

Since 1667 there were plans for reclaiming the Zuiderzee. However, the technical capabilities at that time were not sufficient for construction of the new land. From the moment the steam engine came in use for draining new land (middle 19^{th} century), various studies were carried out concerning the reclamation of the Zuiderzee.

After a number of interim reports, the final report appeared in 1891. It concluded that in the North the soil conditions of the Wadden Sea were unsuitable for agriculture, because they were too sandy. It also indicated that south of the present location of the Afsluitdijk some areas with suitable clay deposits were present. Lely projected polders in those areas. Dr. Lely was a civil engineer who led the technical research team that explored the possibility of reclaiming the Zuiderzee. It was a pleasant coincidence that these areas also formed the shallowest part of the Zuiderzee, so that reclamation was relatively easy. Lely recommended closing off the Zuiderzee first and reclamation of the agricultural land within the protection provided by an enclosing dike. He found that this was a cheaper solution since the polders could then have lower dikes to protect them against storm floods. He also considered the workability would be a lot better if the basin was shut off first. The report concluded that the costs of the reclaimed land would be very reasonable. Summarizing, the anticipated advantages were:

- creation of good quality farmland
- improvement of the protection against flooding
- enhancement of traffic connections
- creation of a fresh water basin

And the disadvantage:

- loss of fisheries

Goals and challenges

In 1918 it was decided that the Zuiderzee polders were going to be constructed. Two main reasons led to this decision. Firstly a period of food scarcity during the First World War and secondly another serious flooding disaster in the southern part of the Zuiderzee in 1916. The Zuiderzee was to be closed off from the North Sea by a barrier dam and that in the resulting IJsselmeer land was to be reclaimed. The accepted plan was made in 1890 and was based on the following objectives (Segeren et al., 1982):

1. Shortening the coastline from 300 km to approximately 30 km to increase the safety of the areas surrounding the Zuiderzee as well as the heart of the Netherlands and to decrease the maintenance costs of the dikes.
2. Reclamation of extremely fertile, flat and well drainable agricultural land.
3. Improved water control in the main part of the country (control of water levels and salinity).
4. Improved road systems for better communication between the western and northern parts of the country.

A challenge was to create support of society. The Zuiderzee act (1918) had limited political and social support. In addition, during construction of the works there was opposition and the project was delayed several times. Since the beginning of the project, there was active opposition by fishermen for losing fishing grounds and by the Ministries of Defence (which considered the Zuiderzee part of the Dutch defense system) and Finance (which feared the costs of the project). In addition, farmers foresaw problems with the drainage of their lands. Even from Rijkswaterstaat there was resistance, as they believed that the assumed national interest could not justify the project development by the state. Later, however, this vision changed to active support of the project.

Another important challenge of creating the IJsselmeer polders related to the planning aspect. Since an enormous area of new land was created, it was a challenge to design the layout of this new land in an efficient and attractive way. A special commission, the “Commissie Inzake Het Bestuderen Van De Uitgifte Der Zuiderzeegronden” was established to investigate the best way of creating a planning for good, modern traffic ways, reserving grounds for public use such as churches, schools, hospitals, parks, cemeteries and in the larger municipalities possibly airports. The most important task of the commission was the socio-legal aspect of the distribution of the land. The commission also emphasized the importance of the timely care of administrative clarity. Each of the Zuiderzee polders had to have an independent waterboard. To make the reclaimed Zuiderzee land immediately habitable, facilities had to be constructed quickly. It came to things like a good drinking water, setting up a health service, the installation of electricity, the location of settlements and the use of land for forests, parks and sports fields. About these issues, there was not always agreement in the commission (Van der Ham, 2009).

Another challenge was the social aspect. In the new land, for example in the Noordoostpolder, not everyone could simply become a farmer. Who wanted to be considered for one of the farms had to pass a strict selection procedure, performed by the national government. The selection was possible since there was an enormous interest in living in the new land. The selection procedure depended in the first place on the knowledge about the technical issues of agriculture and experience in the field, but applicants were also required to have sufficient insight in the economic aspects. In addition, the farmers needed to have sufficient financial recourses. Apart from these requirements, the farmers needed to be personally suitable for being a colonialist in the new land. In general, this means that the candidates also needed to be prepared to contribute to build up the new society, in the general interest of the polder population (Venstra, 1956).

The Markerwaard issue

An important decision concerning the IJsselmeer polders was that the Markerwaard was never constructed. The underlying reasons leading to this are interesting to mention in this study, since some of them should be considered while deciding about new polders. The discussion took place between 1970 and 2006. Many studies have been performed, but each time it was decided that the Markerwaard was not to be constructed. The following developments led to the decision that the Markerwaard is never constructed.

In 1972, an association for preservation of the IJsselmeer was founded: the “Vereniging tot Behoud van het IJsselmeer” (VBIJ). This association was a strong opponent to the construction of the Markerwaard.

In 1980, the government proposed new plans concerning the Markerwaard. Starting point was a polder of 41,000 ha with mainly agricultural purposes. The investment costs were expected to be very reasonable. In the nineties, the works could then be started and around the year 2000, the polder would be finished. In 1982, however, it was proposed to prepare a development plan for the IJsselmeer area, in which all possible usages were investigated. In 1983, the Dutch governmental institution “Rijksdienst voor de IJsselmeerpolders” (abbreviated RIJP), published a report with the goal to gain more insight in the possible development in the Markermeer and as such to give a clear overview of the choices concerning impoldering. This study was seriously criticized. Additional investigations continuously delayed the decision.

Another doubt about the need of impoldering was the question to what extent the Markerwaard would be useful for the agricultural sector. In 1984, research showed that the expectations were much too high; impoldering was not needed for the agricultural sector, neither for the Dutch economy in general.

In 1985, there was a plan concerning private financing of the development of the Markerwaard. The plan seemed profitable, but a study prepared by the government showed that 100% private financing was impossible. Too many costs were estimated too low or were neglected and the financial risks for the government were considered too high.

In 1987, a plan was presented for a reclamation of 23,000 ha of agricultural land in the north-eastern part of the Markermeer. The remaining 37,000 ha was reserved for nature and recreational areas. However, the plan was rejected for other than financial arguments: a small polder would make the realization of a larger Markerwaard impossible. In 1990, the government decided not to reclaim (De Markerwaard, n.d.).

After six years of silence, the province of Flevoland proposed a second national airport in the Markermeer. However, after an extensive social study in 2006, the government published via the “Nota Ruimte” (discussing the future layout of the Netherlands) the decision that the Markerwaard would not be constructed.

To summarize, this description demonstrates that the issue of the Markerwaard has been troublesome. Many different factors led to the fact that the Markerwaard issue could not be resolved. Reasons were the need for maintaining a fresh water reservoir, delay in the decision-making process due to political disagreement, decrease in agricultural needs, wrong estimations of costs, too high financial risks for the government and the fact that a small polder would make the realization of a larger polder impossible. Considering new polder developments in the future, these arguments should be kept in mind.

Table 3.2 gives an overview of the positive and negative effects of the IJsselmeer polder projects.

Table 3.2 effects of the IJsselmeer polder projects

Positive	Negative
Increase of fertile land which leads to agricultural development	Decrease of income for fisheries (however, this appeared to be less severe than originally thought)
Flood control: higher safety levels due to a shorter coastline which is easier and cheaper to maintain	The IJsselmeer polders are used for agricultural and urban development resulting in discharges of wastewater to the IJsselmeer system.
Creation of a nature reserve	
Recreation: sailing, windsurfing, beaches, vacation resorts. Also the polders itself are a tourist attraction	
Industrial: the new land is being used for industrial functions and as a receptor of pollution discharges	
Energy production: power plants are present in the polder that make use of IJsselmeer water as cooling water	
Culture/landscape: certain parts of the coast are protected landscape, various towns are on the world heritage list or are otherwise (nationally) protected	
Urban development and traffic connections: the polders are in the proximity of the so-called Randstad, a densely populated and industrialized area with a shortage of housing and industrial land	
Fresh water reservoir: important for many functions	

Lessons learned

With respect to the anticipated advantages and disadvantages in hindsight, it can be concluded that the project had a tremendous positive influence on safety and on the traffic connections. Due to global economic developments, the creation of farmland is no longer considered so important, although the space created has been used to solve many planning dilemmas in the country.

The availability of a large fresh water basin has become more important than was ever foreseen. Eventually, the fishing industry did not suffer as much as was feared, because fisheries continued in the fresh-water lake and the connection with the Wadden Sea / North Sea remained. Completely unexpected was the present role of the IJsselmeer for recreation. Technical developments in mobility of people (bike, motorbike, car) influence the spatial planning concepts in the various polders strongly.

From a scientific point of view, the spin-off has also been very extensive. The project triggered the start of scientific analysis of coastal and hydraulic engineering in the Netherlands and its application elsewhere in the world. Lorentz developed a mathematical technique for tidal calculations based on linearization of the quadratic terms in the equation of motion, a method that remained in use for many years. The need for technology support to these works led to the establishment of the internationally leading scientific institution Waterloopkundig Laboratorium (WL | Delft Hydraulics; now Deltares). Furthermore, the preparation of the reclaimed seabed for agriculture has led to comprehensive agricultural research (Wageningen University) and much insight has been gained into desalinisation.

Examples of important lessons learned are the application of water bodies separating the new polders from the old land. These lakes were not included in the first polders, which led to drying out of adjacent areas. Another lesson learned in the development of previous polders was the implementation of adequate facilities and infrastructure. In the Haarlemmermeer for example, the lack of facilities and infrastructure led to undesirable situations related to safety and welfare. In the IJsselmeer polders such problems were solved due to a proper planning of constructing infrastructure and utilities. This proved to be a condition to attract people to the new polders, especially in the first years after reclamation.

The social challenges mentioned in the previous sections were an important learning experience. The decision to make the state responsible for the reclamation and planning of the IJsselmeer polders had paid off. The experience gained in the earlier polder projects proved to be of great importance.

The IJsselmeer polder projects have contributed to higher safety levels in the Netherlands. The coastline is shortened, leading to fewer problems in maintaining the land. The IJsselmeer polders are sustainable, because they are not compromising future generations. The nature areas contribute to this. To make the polders more sustainable, a solution has to be found for the energy required for pumping. The IJsselmeer polders set up in a flexible way, since a change from agricultural use to more industrial and urban area was relatively easy to accommodate.

3.4.2 Laguna de Bay, Philippines

Introduction

Laguna de Bay is one of the largest lakes in Southeast Asia and the largest and most vital inland body of water in the Philippines. It spans 90,000 hectares, with around 100 streams draining into it, some even tracing its headwaters to as far off as Quezon province. At present, the lake has an average depth of 2.5 meters. It cradles a region of 283,000 hectares encompassing 6 provinces, 12 cities, 49 municipalities and 2,656 barangays (the smallest administrative units in the Philippines), 187 of which are within lakeshore towns. It is situated in one of the fastest growing economic zones in the country today.

Over the recent decades, population expansion, deforestation, land conversion, urbanization, intense fisheries and industrialization have caused major changes in the Laguna de Bay catchment area. The resulting problems include rapid siltation of the lake, eutrophication, input of toxics, flooding problems and loss of biodiversity. The Pasig River serves as the only outlet of the lake and is connected to Manila Bay. During the dry season, the lake water level may fall to a minimum elevation of 10.5 m (corresponding to mean sea level), and this allows the Pasig River to reverse its flow leading to the intrusion of seawater (backflow) and highly polluted water from the Metro Manila area into the lake.

Through the Netherlands funded “Sustainable Development of the Laguna de Bay Environment“ (SDLBE) project an innovative and technically and financially viable Polder Island Development Plan (PIDP) was realized. It was aimed and designed to address these problems and needs of the most populated and polluted part of the Laguna de Bay basin and to respond to the national government’s programs particularly in terms of water supply and sanitation, macro-economic development, job creation, poverty alleviation social housing and environmental protection. The pre-feasibility phase on PIDP has resulted into a technically and financially very viable plan.

Goals and challenges

The Polder Island Development Plan (PIDP) study consists of four polder islands (Figure 3.3). The most southern island of 800 ha was proposed to become a drinking water reservoir, tapping from Laguna de Bay during the wet season (when the lake has a very low salinity level) to provide a continuous 400,000 m^3/d to address the expected inadequate reliable water supply in the year 2006. The most northern polder island was proposed primarily as a new sanitary landfill for Metro Manila and nearby towns with a portion of the area being used for construction of a wastewater treatment plant. The two middle polder islands were proposed primarily for social housing, thereby reducing congestion related problems in the densely populated shoreline area.

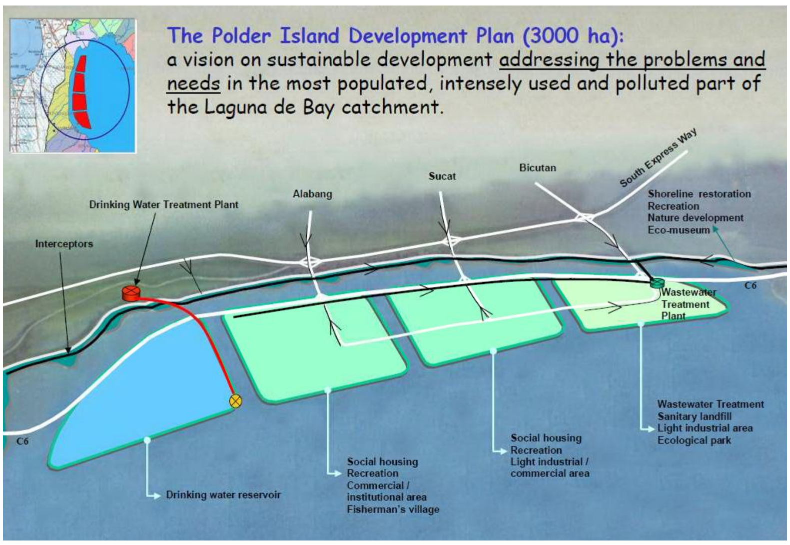


Figure 3.3 The Polder Island Development Plan

Despite its viability, there are significant challenges to be addressed within the PIDP:

- The site selected for the development of polder islands was challenging with respect to engineering design and construction. The peak ground acceleration during earthquakes is high: the expected acceleration with a 10% change of exceedance in 50 years is between 0.3 and 0.6 m/s^2. The subsoil consists of thick layers (5 to 15 m) of soft mud, which may settle up to 4 m if a surface load equivalent with a 10 m body of sand is applied. The shear strength of the mud is low; resulting in a high risk of failure of these layers during earthquakes. Improvement of the subsoil or deep foundations is required for a safe design.
- As the costs of the total scheme may be too high to handle by the Government alone; the private sector will have to be involved. By doing so, this may change the scope of the project and the focus will shift to the most financially feasible and straightforward components like water supply and the development of industrial areas.
- It will be difficult to control the illegal settling at specific open areas (no man's land) meant for dike maintenance and therefore safety purposes.
- It will also be challenging, given the complex political system in the Philippines and the specific interests of key players like local mayors and the provincial governor to reserve budget for these maintenance and repair activities.

Lessons learned

The most important reason that the project has not been implemented yet relates to the fact that the total investment required is beyond the financial means of the Philippino Government. Hence, the concept of flexibility was introduced by constructing the project in different subsequent phases (Figure 3.4). Each project phase was divided in a feasibility study and a bidding/construction phase and assume the . Even though the project was split in phases, it was stalled due to a change in leadership and a changed focus on the national priorities.

In general, it was recognized that it will be difficult anyway to implement projects that will not materialize within the terms of the political leaders.

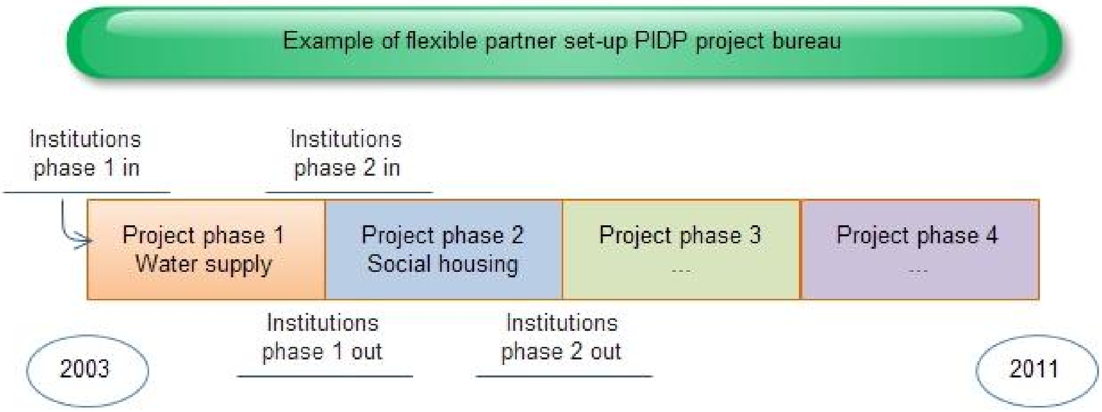


Figure 3.4 Example of flexile partner set-up PIDP project bureau

Conclusions

Obviously, the polders have been designed to create a much higher safety level for flooding compared to the overpopulated mainland area. The whole project is also designed to achieve sustainable development of the area.

Flexibility is an important aspect of the project as well, since the functions of the various islands have been designed in relation to possible future needs. To overcome the current lack of drinking water reservoirs it was e.g. decided to reserve one of the polder islands for freshwater storage. However, it was realized that after the construction of a new reservoir north of Metro Manila in 10 to 15 years time this polder storage would not be needed anymore. After close consultation with the adjacent municipalities it was agreed to reserve the new land for social housing. Similar arrangements were made with municipalities adjacent to the sanitary land-fill island. It was agreed that after capping this island could be used for leisure and recreational activities (e.g. a golf course).

3.4.3 Polder development in Singapore

Introduction

The long-term master plan for Singapore (URA, 2008) ensures there is sufficient land to meet anticipated population and economic growth, and to provide a good living environment.

To address the rising demand for more land, large scale reclamation has been undertaken in different parts of Singapore since the 1960s. To date, the traditional landfill method was used to reclaim land at the coast and swamps in order to extend the size of some islands. The first reclamation works made use of fill materials from the hills, while more recent reclamations made use of sea sand. Due to limited availability of sand or other fill material, new land reclamation projects will be difficult to sustain in the long term. It is for this reason that the Singapore Government decided to carry out a conceptual design study for reclamation works based on the polder systems, thus reducing the total required volume of fill material compared to traditional reclamation.

Another limiting factor for reclaiming new land in the coastal areas of Singapore relates to the depth of the coastal waters. In the past, land reclamation works used to be carried out from depths of 5-10 m. Nowadays, reclamation works have to be carried out in deeper waters of about 15 m which implies much higher costs.

Goals and challenges

In a conceptual design study, see Figure 3.5, a stepwise approach was followed that allowed for a gradual transfer of knowledge of polder technology. During this process, in which most important agencies participated, a number of issues of concern were addressed, see Table 3.3.

Table 3.3 Interests/concerns of the various stakeholders

Interests/ concerns of the various stakeholders
Legal issues
Environmental impacts on marine aquaculture of the polder concept
Functional use
Technical, environmental and cost implication on polder development
Transboundary effects
Effects on navigation
Environmental impacts
Nature conservation and marine biodiversity
Land use planning
National water supply / reservoirs
Land ownerships

A major challenge in Singapore is to address the environmental concerns and transboundary impacts of new reclamations.

Another issue for polder development in Singapore concerns the psychology of living below sea level. As mentioned above, the only reclamation method applied in the past was raising the sea bed. The way of creating new land by using the polder concept is new to Singapore, leaving doubts about the safety of this method. People are afraid of failure of the system and the recent flood events in downtown Singapore are not very helpful in this respect.

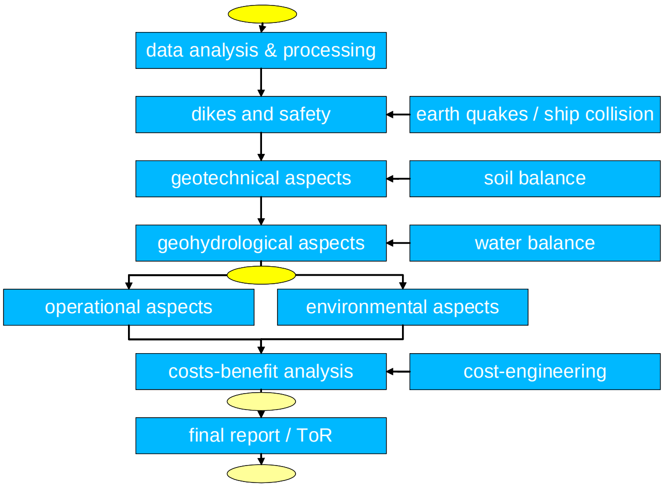


Figure 3.5 Components of the conceptual design study

Another problem that is to be considered when designing polders in Singapore is the occurrence of adverse water quality due to stagnant water in polder ditches, leading to mosquito breeding places. Related to the high temperatures and high precipitation rates, this problem is much more relevant than in the Netherlands.

Institutional setting

As mentioned above, land is scarce in Singapore. The goal of urban planners is to maximize use of land efficiently and at the same time comfortably. As many people as possible are to be served for a particular function, such as housing or commercial purposes in high-rise and high density buildings. Infrastructure, environmental conservation, enough space for water catchment and land for military use are all considerations for national urban planners. The urban planning policy demands that most buildings being constructed should be high-rise, with exceptions for conservation efforts for heritage or nature.

Urban development in Singapore is top-down oriented. The majority (more than 80%) of Singaporeans live in public housing. These homes are located in housing estates, where most are developed neighborhoods with schools, supermarkets, clinics, food centers and recreational facilities. The Housing and Development Board (HDB) has been the largest housing developer for the past three decades (Groves et al., 2007).

Conclusions

Due to sand shortage polder development in Singapore can be, an alternative for traditional land reclamation. However, an important concern is that people are not used to live below sea level. Related to this, high safety levels are required. Concerning sustainability decrease of ecological value and full utilization of each square meter has to be compensated by applying specific types of dike materials that support ecological development. In case urban development is not the main reason for polder development the polders need to be designed in such a way that this function can be accommodated in the medium to longer term due to the ever increasing need for land to house the estimated future population.

3.4.4 Banger polder, Indonesia

Introduction

The Banger area is a sub district of East Semarang, on Java, Indonesia. Its size is 530 ha and the population is 84,000 inhabitants, which implies a high population density of 16,000 people per square kilometer. The income of 48% of the inhabitants is below the poverty line. The main infrastructure consists of railways, a main road to the harbor, the highway Jakarta-Surabaya and a harbor.

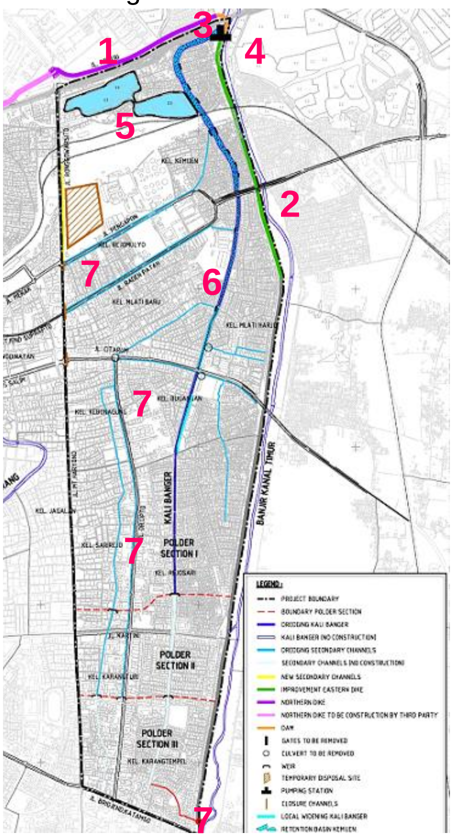


Figure 3.6 Overview of the project area

Flooding problems aggravated by subsidence occur frequently and affect companies, households, railways and roads.

Figure 3.6 gives an overview of the project area. The project includes the following components:

1 Northern dike
2 Eastern dike
3 Dam to prevent inundation from rainfall
4 Pumping station
5 Retention basin
6 Excavation Kali Banger
7 Sub- water system

In 2003-2004, a feasibility study was performed to investigate the possibilities for using the Banger area as a pilot area for polder development. The city of

Semarang was chosen for such a polder development project, mainly because of the governmental willingness to participate. The project proved to be technically and economic feasible. In 2009, the design for the polder was ready and in the same period, a polder board was set up (“Pilot polder Semarang”).

Goals and challenges

The main goals of the project are to prevent the severe floods and to overcome the daily nuisance of minor inundation. Another important goal is to show that the concept of polders is working for Indonesia, especially from an organizational point of view.

There are several challenges to overcome in the area. In the first place, a technical challenge is the high subsidence rate of approximately 9 cm per year. However, the most important challenge seems to be the institutional setting. The cooperation between different authorities is extremely difficult. This is partly caused by the fact that not all stakeholders were involved during the preparation phase. A related problem in the project is that there are too many parties involved. The result of this is that the communication between the different parties is quite demanding.

Another challenge is to find space for retention basins. The railway company owns the area that is most suitable for retention. Hence, discussions arise about the use of this land. For the polder to function properly the land should be used for retention.

To address the institutional issue a water board was established to manage the future pilot polder. It is being overseen by the Dutch water board of Schieland and Krimpenerwaard. The new water board consists of eight people, including three local residents, three professors, and two people representing the authorities. There was a ceremony in April 2010 at which the Mayor of Semarang, the Governor of the Central Java province, and the Secretary General of the Ministry of Public Works signed treaties for transferring powers to the water board – some of which are far-reaching by Indonesian standards. The water board will devise, write, and introduce all rules, procedures, and protocols necessary to ensure the proper working of the polder.

The ongoing project activities include:

- Construction of dikes
- Building of pumping stations
- Dredging of rivers to create more drainage capacity
- Revitalising the drainage system in the city
- Controlling solid waste
- Constructing storage basins

Polder development is considered to have a positive economic impact on the area. In the first place, the damage on houses, roads and railroads will decrease significantly. There will also be a large indirect influence, for example decrease in traffic jams and decrease in production losses. In addition, there will be a positive effect on public health, as the number of ill people will decrease by an estimated 5%.

The Netherlands is involved via different stakeholders. Witteveen+Bos is involved in the technical aspects and supervision of the project. They were selected after a seminar that the company organised in Jakarta in 2001 for an audience that included representatives of the Indonesian government. Witteveen+Bos prepared these activities in cooperation with the Indonesian parties and was responsible for the plan phase and feasibility study all the way through to the design and specifications. The water board of Schieland and Krimpenerwaard became involved in providing assistance in the institutional process. It has an important task in the development of the polder board. Unesco-IHE is involved in the project by contributing to the design guidelines. Partners for Water supports the program financially.

Conclusions

Obviously, applying the polder concept in this situation implies that the area is flooded less often, resulting in higher safety levels and better living conditions. The project is economic sustainable. Controlling waste is a sustainable development. Flexibility is taken into account by creating more drainage capacity and the construction of large retention basins, to cope with changes in future in rain water discharge and further subsidence of the area.

3.4.5 Subsidence reversal in Louisiana, USA

Introduction

In 2008, a Dutch consortium consisting of DHV, Deltares and Imares proposed for a pilot project on marsh creation in Louisiana. In January 2009 the pilot project started. This project was funded by the Dutch government (Ministry of Economic Affairs).

Various types of marshlands characterize the coastal area of Louisiana. These marshlands are threatened by fragmentation, invasive species, subsidence, pollution and changed water circulation. One of the major factors contributing to marshland loss is the dikening of the Mississippi River. After completion in the 1950’s, the river was confined within the dike system to prevent flooding. However, this also stopped the nourishment of the marshlands with sediments and nutrients. Without this nourishment, the combined effect of sea level rise and subsidence exceeded the rate of natural marsh growth and marsh loss began.

There are numerous problems threatening Louisiana’s marshes and methods for rapid marsh restoration are considered urgently needed. Currently, two methods for marsh restoration are regularly applied. First, diversions of the Mississippi River are created to increase input of fresh water and sediments. Second, dredged material is used for increasing elevation of marsh platforms and filling in shallow open water areas. These methods are successful, but they are relatively expensive and do not allow very precise manipulation of conditions. Furthermore, if the result deviates from the desired objective it is hard to make adjustments to the chosen strategy. Therefore, a third and more ‘controllable’ technique, such as the proposed subsidence reversal technique, described in the following paragraph, was considered desirable.

In short, the subsidence reversal technique consists of construction of a closed dike system in an open water body. Water will be pumped out to a level that allows vegetation regrowth. Next, water management will be optimized for peat formation. The ultimate goal is to create a marsh system that will survive without the presence of the surrounding dike. The technique is expected to have several benefits compared to other methods of marsh restoration. First of all, other techniques are not suitable for restoration of the characteristic Louisiana organic freshwater marshes. The subsidence reversal technique is expected to allow restoration of this type of marsh and offers good opportunities for adaptive management. Next to this, it is expected that management will be relatively low and pure manipulation of water levels will be sufficient to create valuable and low maintenance natural areas.

Goals and challenges

The objectives of the project are:

- to convert open water areas to a self-sustaining marsh system
- to test a new method for marshland restoration applicable in freshwater areas throughout coastal Louisiana

The marsh system is used to enhance the safety of the urban area of New Orleans. The mechanism behind this is the decrease in open water, leading to the situation that waves are not able to build up and overtop dikes.

Figure 3.7 depicts the process of polder design. The first step is to create a polder dike and a pumping station. The pumping station pumps out the water. When the polder is dry, vegetation can be regenerated. The new grown vegetation is used as a "natural carpet" when slowly fresh water is let in. The "carpet" starts to float and the natural water level can be restored and connected. The complete process will take about 10-15 years.

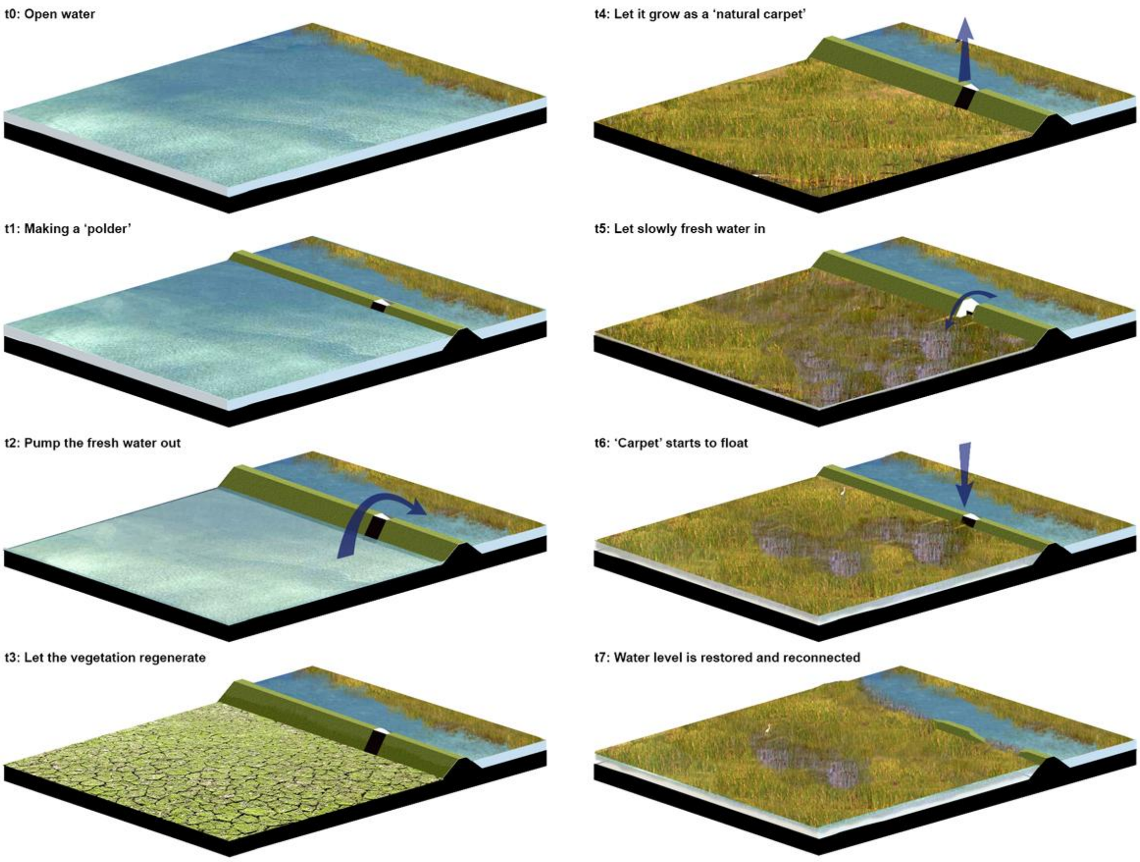


Figure 3.7 process of polder design

The following basic design assumptions were used for the general lay-out of the polder (Figure 3.8).

- Location of dikes based on old dike locations
- One main junction canal parallel to the dikes
- One pumping location
- Crest not accessible for cars or trucks

Figure 3.8 Layout of the polder

The total area of the polder is about 40 ha. The water level within the polder should follow the increasing bed level. Initially the bed level is 1.5 m. below the initial water level. In order to get the polder dry, pumps will be used. Once the polder is dry, the pumps will be used to get rid off rainwater. Because the dike is impermeable and the crown height is sufficient to prevent wave overtopping, rainfall forms theoretically are the only import factor of water into the polder system. The pump capacity is based on a rainfall intensity of 0.19 m within 12 hrs. With respect to hurricane Katrina where more than 0.46 m felt within 24 hrs, this is a moderate rainfall intensity. In order to determine the required non-variable pump capacity the following design assumptions have been used:

- Polder dry within 72 hrs after start rain;
- Rainfall: uniform distribution (190 mm within 12 hrs);
- One pump;
- No evaporation or infiltration;
- No seepage water (impermeable dikes);
- No wave overtopping.

Role of the Netherlands

In order to ensure the further development and implementation of future phases of the project a governance model is proposed as depicted in Figure 3.9 and described below.

The Steering Committee would include one representative from each of the following: the Louisiana Office of Coastal Protection and Restoration; the Jean Lafitte National Park; the US Army Corps of Engineers; Rijkswaterstaat; Jefferson Parish, the Stakeholders; and the Project Sponsor(s). Note: the Project Sponsor(s) would be entities providing funding for the project. The Steering Committee would be responsible for providing guidance and direction to subordinate committees; ensuring continued funding for all phases of the project; making final decisions concerning operational management of the project and other issues, policies, and procedures necessary to make the project a success. The Steering Committee would make decisions in consideration of recommendations from the Construction Committee, Scientific Committee, the Operational Management Committee, and the Stakeholders.

The Scientific Committee would be comprised of representatives from Deltares (NL); Imares (NL); USGS, National Wetlands Research Center; the LCA, Office of Science and Technology; the University of New Orleans; and Louisiana State University. This committee would develop and implement a monitoring program; direct research; and make recommendations to the Steering Committee concerning the Operational Management of the project. The Construction Committee would include representatives from the Louisiana Office of Coastal Protection and Restoration; the US Army Corps of Engineers; and Rijkswaterstaat. This committee would be responsible for ensuring proper design and construction of the project including the dikes and pumps. Any maintenance required during the project life also would be the responsibility of this group. Operational Management of the project would be the responsibility of the Jean Lafitte National Park and the Project Sponsor(s) (Van Dam & Mulder, 2009). Figure 3.9 gives the organizational structure of the project.

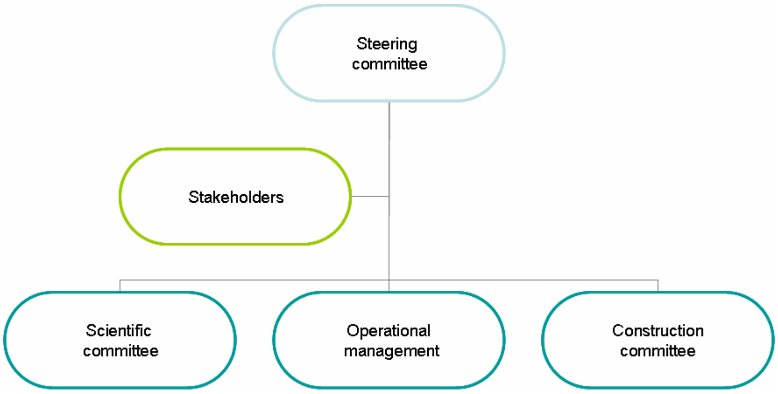


Figure 3.9 Organizational structure of the project

Conclusions

At the moment, the project is in an early phase but in a few years the results will become available. From this case study, which is completely different from the other case studies, it can be concluded that the concept of polders could be a possible manner to enhance the safety of existing urban areas. Unlike the other mentioned urban polder projects it is not a urban polder itself, but a method for nature development leading to increased safety levels in the adjacent urban area.

As the pilot project appears to be feasible, the scale of safety enhancement is expected to increase with more and / or larger polder systems. Concerning sustainability, this polder is a sustainable development making use of natural mechanisms. The concept of “Building with Nature” is applied (discussed in Chapter 4). The concept of flexibility is also part of the project. The function may change in time from new marshland to mature nature development.

3.5 Cross case analysis

The following table gives the aspects related to safety, sustainability and flexibility observed in the different case studies.

Table 3.4 Cross case analysis

Aspects \ Case study	The Netherlands	Philippines	Singapore	Indonesia	USA
Safety					
Shortening the coastline	X				X
Flood prevention	X			X	X
High safety levels	X	X	X		
Sustainability					
Nature development	X				X
Improvement of transportation/traffic connections	X	X		X	
Reduction of congestion related problems		X			
Improved living environment by improved sanitation		X		X	
Direct economic development in the area	X	X		X	
Application of the concept of “Building with Nature”			X		X
Flexibility					
Functional change from rural to (future) urban area	X		X		
Functional change to marshland to protection of urban area					X
Recreation and tourism enhancement	X	X			
Fresh water reservoir part of the project	X	X	X		
Population growth considered	X	X	X		
Flexible institutional setting		X			
Climate change considered			X	X	X

3.6 Conclusions

Polders are found everywhere in the world. However, most of them are relatively unknown compared to the polders in the Netherlands. This is caused by the fact that the total covered area by polders and the number of polders is much higher compared to other countries. Furthermore, the Dutch have been developing polders since many centuries in order to sustain. The knowledge to construct polders is therefore amply available within the Netherlands. This creates business opportunities for the Netherlands for utilizing the polder concept abroad.

The case studies that have been described mainly show positive effects. From the case studies, it can be concluded that the best opportunities for polder development are to be found in urban areas. In dealing with climate change (e.g. more extreme rainfall), sea level rise and subsidence, existing urban areas can be protected by applying the polder concept. In addition, the polder concept can contribute to create new space needed to address the ongoing urbanization in delta areas.

From the case studies it became clear that three factors are of high importance to the success of polder development. The most important aspect is the institutional setting. Without a proper institutional body, the long-term operation and maintenance requirements can not be met. In the second place, the financial capacity is of importance. Sufficient financial resources should be available in order to let the polder sustain. Both for construction as in operation and maintenance, money must be available. For example, the project in the Philippines is never implemented partly because of lack of financial capacity. In the third place, the availability of resources is an important factor that relates to the success of polder development. In case of sufficient availability of filling material, heightening of the area might be the preferred option from an economic and sustainable point of view. In that case, the operation and maintenance requirements are less and high safety levels are easier to achieve. In the case of lack of recourses, such as in Singapore, land reclamation through applying the polder concept might be the only option.

4 Design considerations for urban polders

4.1 Introduction

The previous chapters have shown that opportunities for polder development lie in protection of existing urban areas. The case study in Indonesia describes the situation of applying the polder concept in an existing urban area. The project seems successful so far. However, an important aspect remains the administrative responsibility for the management of the polder.

This chapter will further discuss the design considerations for urban polders. Based on the findings in the previous chapters, three main issues are considered: safety and risk, sustainability and flexibility to adapt to future changes.

4.2 Safety and risk

In this chapter, the problems related to safety and risk are being considered. It is evaluated how these problems can be solved. As a visualization, a problem and solution tree are presented. In the subsequent sections, the methods for solving a motivated selection of problems are elaborated.

4.2.1 Definition

The definition of safety used in this research is the condition of being protected against physical, social, spiritual, financial, political, emotional, occupational, psychological, educational or other types or consequences of failure, damage, error, accidents harm or any other non-desirable event. Obviously, in the case of polder development not all mentioned consequences are relevant.

A frequently used definition for safety risk is the chance (or probability) of a particular event and the impact (or consequence) that the event would cause if it occurred.

4.2.2 Problem and solution tree

The idea of the problem trees is to visualize the problem and its possible solutions. The causes of the problem are listed below the problem and the effects of the problem are mentioned above the problem. Then, in the solution tree, all components of the problem tree are reversed. The problem is converted to a goal and the causes to solutions of the problem. The effects of the problem are transferred to sub-goals of the solution.

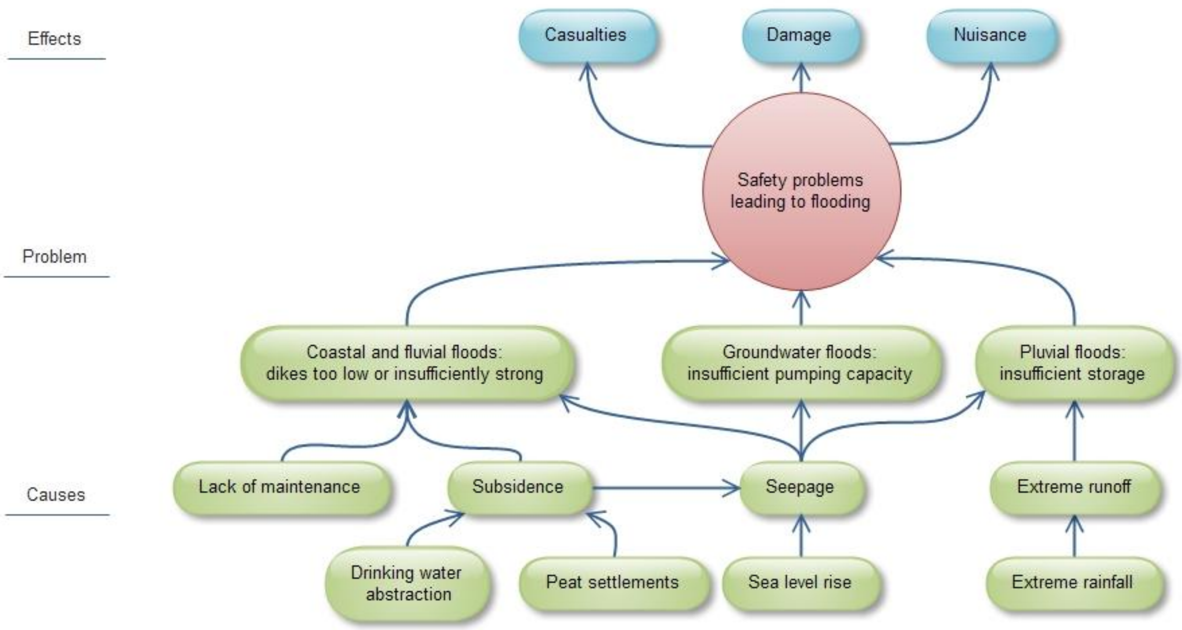


Figure 4.1 Problem tree safety

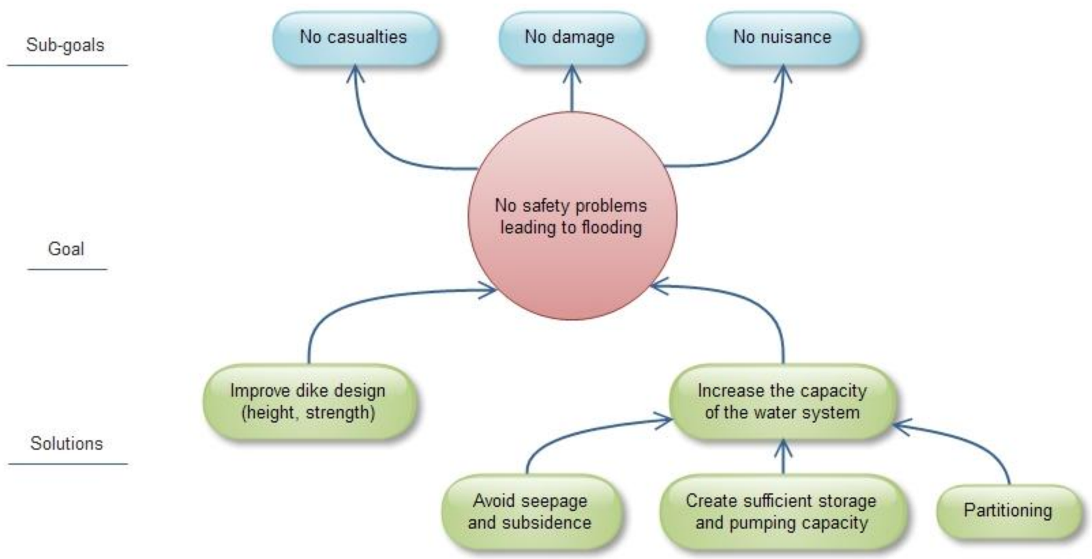


Figure 4.2 Solution tree safety

Four different types of floods have been mentioned in the tree: coastal floods, fluvial floods (caused by rivers), groundwater floods and pluvial floods (caused by excessive rainfall within the area). The causes differ per type. Al four types of flooding are possible to occur in polder settings. Avoiding seepage and subsidence will be discussed in Section 4.3, since these solutions are also related to sustainability.

4.2.3 Improve dike design

Failure mechanisms

From the problem tree, it is visible that in some cases safety problems in polders are caused by coastal and fluvial floods. The solution to this type of safety problems lies in the dike design, it is one of the most important aspects of safe polder development. Figure 4.3 shows the different failure mechanisms that have to be considered when designing polder dikes. In this section, various methods to prevent dike failure will be addressed.

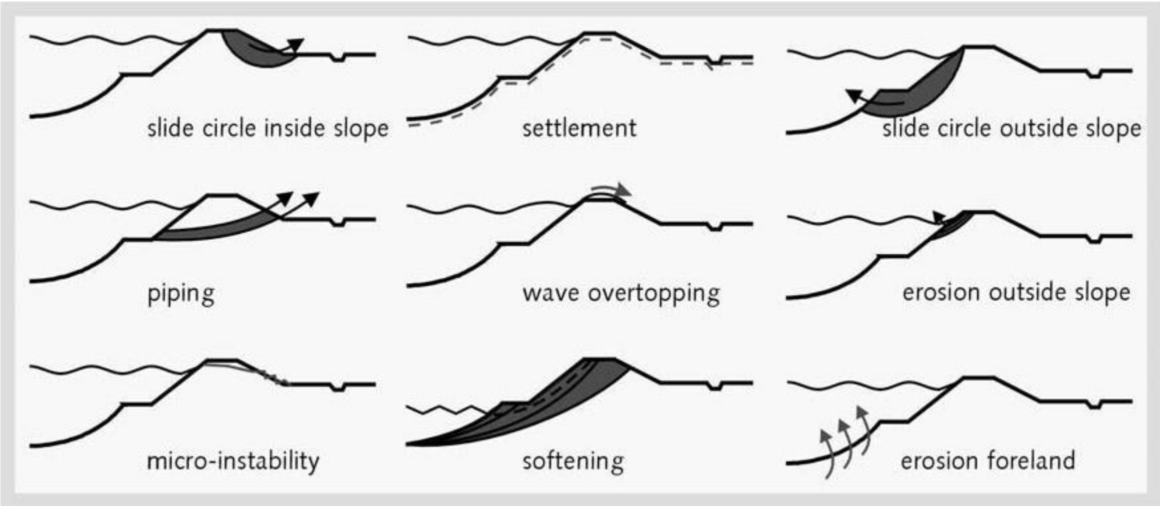


Figure 4.3 Dike failure mechanisms

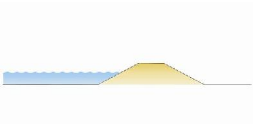
Smartsoils

The concept of SmartSoils is an example of a measure that is suitable in particular polder settings. The idea of SmartSoils is changing the physical and mechanical properties of the original soil material by influencing and speeding up the natural processes that in principle cause these changes. However, it should be mentioned that in the first place the dike has to be proper designed. In case of dike maintenance, the SmartSoils principle may be applied.

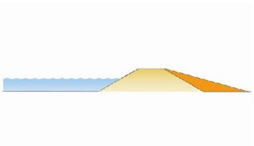
The concept of SmartSoils consists of three elements: BioPeat (enhancing properties of peat soil), Biosealing (decrease of local seepage) and BioGrout. In terms of safety against flooding, BioGrout provides opportunities for increasing the safety levels of dikes. BioGrout is the process by which bacteria control the precipitation of calcium carbonate while consuming supplied reagents. By controlling the amount of reagents, the amount of calcium carbonate and thus the strength of the reinforced sand body can be engineered. The main advantage of BioGrout is that soil (or sand) can be strengthened, without interfering with the hydraulics of the treated soil and without excavation or replacement. The result is a stiffer sand layer with a higher bearing capacity, higher resistance against erosion and higher resistance against shear forces. The higher strength can protect under water slopes against liquefaction and breaching but can also protect dunes or river bends against erosion, reduce costs for wave protection measures (stone protection) etc. (Van der Ruyt & Van der Zon, 2009).

Climate dikes

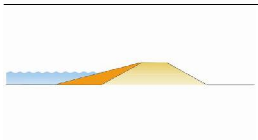
This section gives some examples of the application of climate dikes for both new polders and existing urban areas. In existing urban areas and when space is not limited, dikes can be upgraded to climate dikes; in new polders such types of dikes can easily be considered. The idea behind climate dikes is to create flood defenses that are so robust that they are virtually impossible to breach even under future climate change conditions. Climate dikes allow some wave overflow and even limited flooding, but all types of dike failure as presented in Figure 4.3 are not expected to happen. As safety is a critical design aspect in urban polders, the concept of climate dikes is very well applicable in polder settings. Moreover, in many cases the climate dike may be used for multiple functions. This means an integrated approach is possible, leading to an increase of possible benefits.



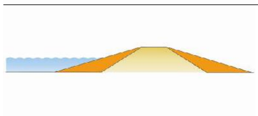
Reference situation. The dike in this situation is not sufficiently strong or high to protect the area from flooding.



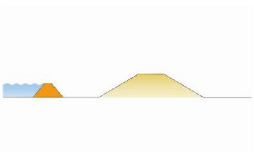
Application of a mild inner slope is applicable in both rural and urban areas. The space on the inner slope can be used for other functions.

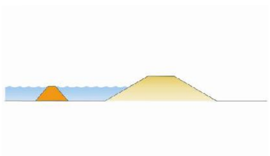


Since the widening takes place on the outside of the dike, this solution is best suitable for lakes or other locations in which the space is available on the waterside.

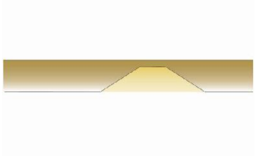


Widening on both sides of the dike can be applied in combination with other functions.

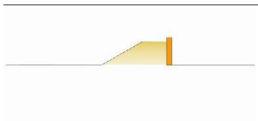




Several options are possible: two or more parallel dikes, a low quay in front of a high dike or breakwaters along the shore. Suitable for polders in which multiple functions are combined.



Camouflaged dikes can perfectly applied in urban areas coping with lack of space, since the dike can be used for multiple functions such as infrastructure, living, working and recreation. An important advantage is that this type of dike is earthquake proof.



This type of structure is especially suitable for urban area, since it can be implemented using only little space. In addition, it can be used for other functions that are incorporated in the dike (Klijn & Bos, 2010).

4.2.4 Partitioning

Partitioning is dividing a dike ring in two or more smaller dike rings. Klijn et al. (2009) define the main objective of partitioning as to reduce the area that becomes flooded, primary from the idea that the flooded surface area is very much related to the damage of flooding and the degree of social disruption. The aim is to reduce flood risks by limiting the consequences. From this description, it becomes clear that partitioning is a measure to reduce the consequences of a flooding event. Table 4.1 (Asselman et al, 2008) shows an overview of some arguments in favor and arguments against partitioning of polders.

Table 4.1 Arguments concerning partitioning

Pros	Cons
Decrease in flooded area, decrease in economic damage and lower expected numbers of casualties	High costs of construction and preservation of the partitioning dikes, this money could be used for better primary dikes
Additional elevated areas, at shorter distance, that can serve as a refuge for people and animals	Increased risk of drowning in smaller compartments, due to rapid water level rise to greater depths compared to the situation w/o partitioning
	Insufficient space for a second embankment sufficiently far from the primary dike, especially in densely populated areas

In polder development projects it has to be considered if partitioning is required, related to the dike safety as mentioned in the previous section. In case of sufficiently safe dikes, partitioning may not be profitable. However, the concept of partitioning may also be applied in another way. An innovative manner of utilizing the polder concept based on the principle of partitioning is the protection of important utilities, such as hospitals or power stations. The aim is to create a higher safety level against flooding for these utilities only. This can be achieved by developing compartments at these flood prone sites. Local safety increases by building dikes around the utilities and installing a pumping station. In case of high water levels, this concept would prevent disruption of society since basic utilities are available during flood periods.

4.2.5 Increase the capacity of the water system

Create sufficient water storage

As can be seen in the problem and solution tree, safety issues related to groundwater influx and rainfall can be solved by considering sufficient storage capacity of the polder water system. The main objective of the polder water system is to keep the water level within a tolerance range that is related to the utilization of the polder. This implies that, regarding groundwater and pluvial floods, urban polder water management systems should meet the following objectives:

- Sufficient drainage and storage capacity to deal with excess rain or flood water;
- Appropriate protection measures implemented to safeguard against local flooding;

The water system is responsible for the water quality in the polder as well. This will be discussed later in Section 4.3.

In an urban polder, the primary function of a water management system is drainage, namely the temporary storage and discharge of the water. A general procedure for determining the water management system is visualized in Figure 4.4 and Table 4.2.

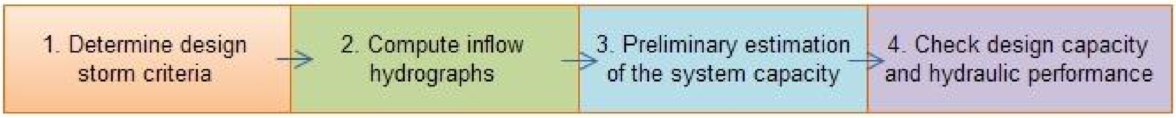


Figure 4.4 Steps for determining the water management system

Table 4.2 Description of the procedure for determining the water management system

Step	Description
1. Determine design storm criteria	The design storm criteria depend on the local climate. Rainfall intensity, duration and return period have to be taken into account. Depending on the local requirements, a normative design storm return period has to be chosen.
2. Compute the inflow hydrographs	The inflow hydrographs for the required storm return period have to be computed. Figure 4.5 gives an example of such an inflow hydrograph.
3. Preliminary estimation of the system capacity	Based on the computation of peak inflow and outflow hydrographs, a preliminary estimation of the required water management capacity may be obtained. This step includes all water management components.
4. Check design capacity and hydraulic performance	This step includes mathematical modelling of the system. If necessary (in case the hydraulic performance turns out to be insufficient), the capacity of the water system can be improved.

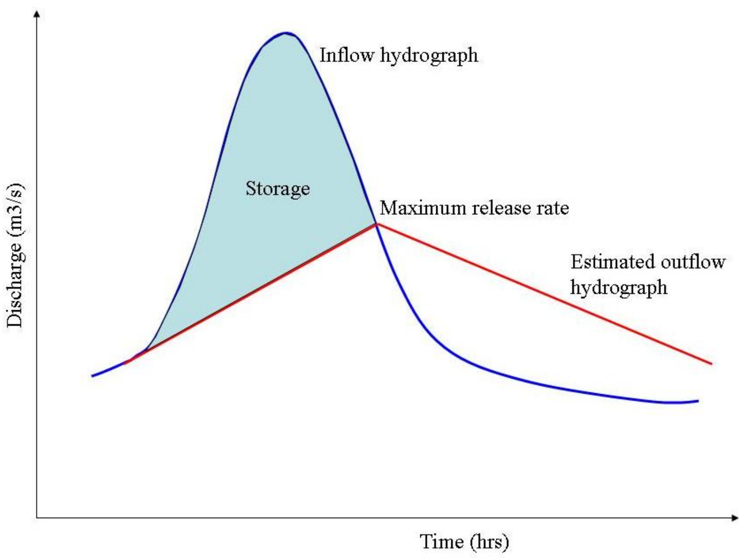


Figure 4.5 Inflow and outflow hydrograph (urban polder guidelines, 2009)

From the hydrograph (Figure 4.5) it can be seen that storage is an important aspect of the polder water system (obviously depending on the local circumstances) in order to prevent flooding. Storage can be achieved in various ways. The simplest solution is to create surface water storage in for example ditches, wetlands and ponds. A storage pond can be constructed by excavating a basin in the ground. A storage basin needs to have at least one outlet. In most cases, the pond is a low-lying area that is designed to temporarily hold a set amount of water while slowly draining to another location.

However, in urban areas space for storage ponds is in most cases scarce. This implies that innovative storage solutions have to be considered when designing new urban polder water systems.

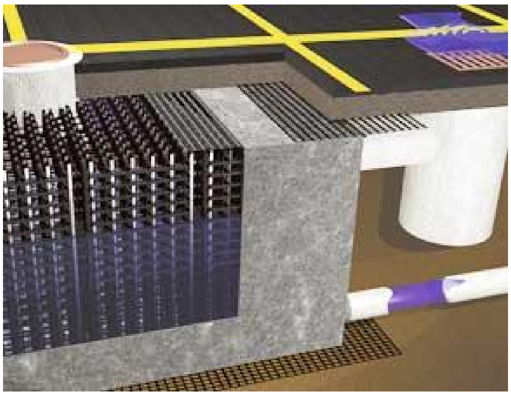


Figure 4.6 Underground water storage (source: www.invisiblestructures.com)

An example of alternative floodwater storage is the application of underground storage. This can be applied in various ways. Figure 4.6 shows an example of stormwater storage below porous pavement. In this way, no additional space is required for surface water storage. Typical storage volumes amount up to 94% of the volume of the installed structure.

Another example of underground stormwater storage is the Stormwater Management and Road Tunnel (SMART), which is applied in the centre of Kuala Lumpur. The system is able to store large volumes of floodwater. This will reduce the flood water level in other parts of the city. The system has different modes, related to the required stormwater storage. In the first mode (normal conditions), no stormwater is stored. In the second mode (most storms), the bypass tunnel contains water and the road is open. In the third mode (extreme storms), the road is closed to all traffic.

Figure 4.7 Stormwater storage in a tunnel (source: www.smarttunnel.com)

Next to these examples, there are plenty other possibilities of (underground) storage that can be considered when designing an urban polder water system. Underground storage is however not in all cases applicable. In case of high groundwater tables, underground storage reservoirs may be filled up partially during an extreme rain event, abolishing the effect of the storage volume.

Create sufficient discharge capacity

In addition to storage, drainage and discharge capacity are important aspects of the design of an urban polder water system. The discharge capacity is determined in relation with the retention capacity, since both form a balance to withstand extreme rainfall events. The higher the pumping capacity, the smaller the required storage area to reach the safety level. Or: a larger retention area requires less pump capacity. The optimal combination depends on several factors. For example, the use of the storage water reservoirs; if these can be combined with other functions such as nature development or recreation, preference shall be given to a larger area of open water. If for example space is limited and is to be used for housing, preference shall be given to underground storage and a higher pumping capacity. However, the economic optimal combination is always a specific pump capacity in combination with a specific storage area. Figure 4.8 gives an example of a purely economic based storage calculation. The figure gives the Net Present Value of the investment of the pumping station, the retention basin, the yearly benefits, and the total. In this example, the optimal pump capacity is 6 m^3/s.

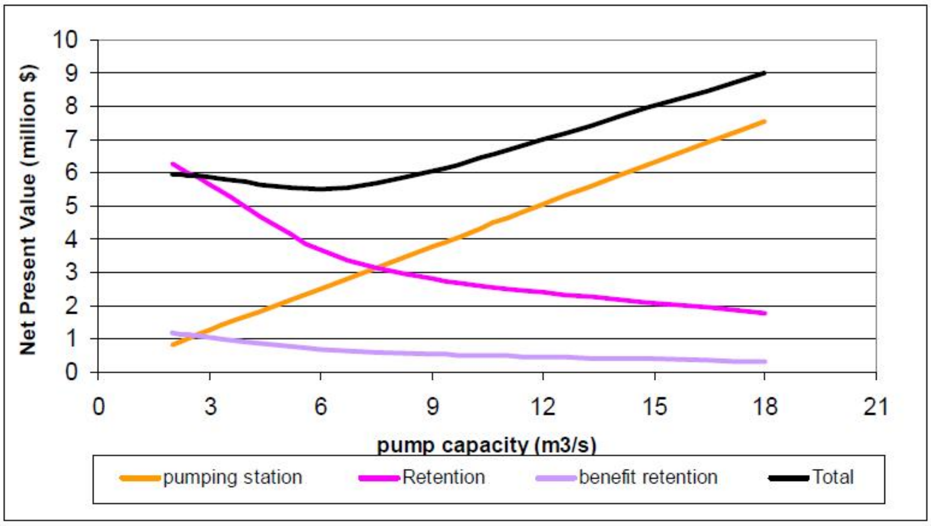


Figure 4.8 Example of a pump capacity calculation graph

4.2.6 Conclusions

From the SWOT analysis, see Chapter 2, it became clear that polders require a high safety level. The aim of this section was to give innovative solutions that increase safety levels of polder areas, by prevention of pluvial, fluvial and groundwater flooding. Depending on the local setting (hydrological, geotechnical, spatial demands, etc.) various technical solutions have been discussed. Climate dikes may be applied in order to provide sufficiently safe dikes. In case of dike maintenance, the strength of the dikes may be increased by application of the SmartSoils concept. Another technique that can be used to increase local safety levels is partitioning. The concept of partitioning is not new, but it can be combined with the polder concept. In this way, the polder concept provides protection of important functions such as utilities. Then, stormwater storage is an important aspect in urban polder settings. Various ways to provide storage have been discussed. It may be concluded that using surface water is the most straightforward way of creating storage capacity. However, in urban areas in which space for such facilities is lacking, underground storage may be considered. Underground storage is applicable in places in where groundwater tables are sufficiently low. A combination of storage and pumping capacity may be computed by using the inflow and outflow hydrographs.

4.3 Sustainability

4.3.1 Definition

A definition often used for sustainable development is development that "meets the needs of the present without compromising the ability of future generations to meet their own needs". It deals with two key concepts:

- The concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and
- The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (United Nations, n.d.)

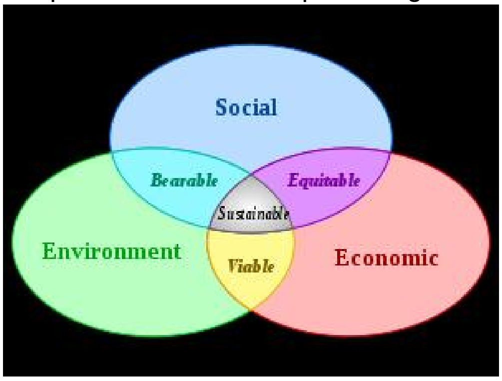


Figure 4.9 Three aspects of sustainability

In 2005, the United Nations developed a definition in which it was noted that this requires the reconciliation of environmental, social and economic demands - the "three pillars" of sustainability. In the following figure the relation between these pillars is given. Sustainable development takes place in the confluence of the three parts ("Sustainable Development", n.d.)

During the brainstorm session, all participants agreed that the polder concept itself is not a very sustainable development (considering subsidence and pumping requirements). However, in many cases the polder concept is an attractive alternative compared to other land use developments. Safety issues, as addressed in the previous sections, are most important for future polder developments. Nevertheless, a major challenge is to develop future polders as sustainable as possible. In this section, the three aspects of sustainability will be considered. The goal is to enhance these aspects resulting in development of future polders as sustainable as possible. Firstly, a problem tree and solution tree will be presented to point out what the causes and effects of unsustainable polder development are.

4.3.2 Problem and solution tree

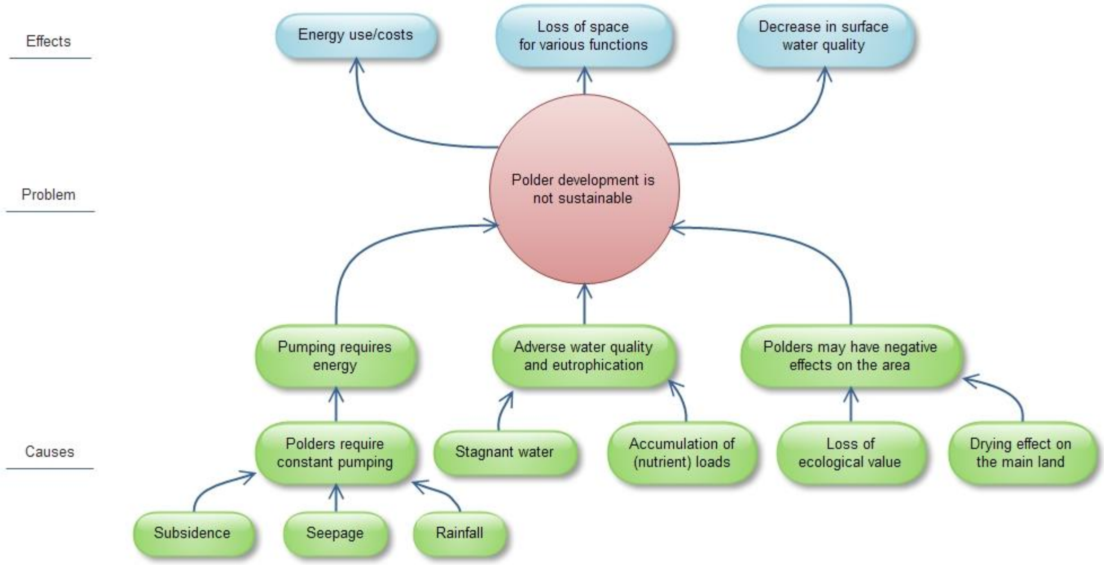


Figure 4.10 Problem tree sustainability

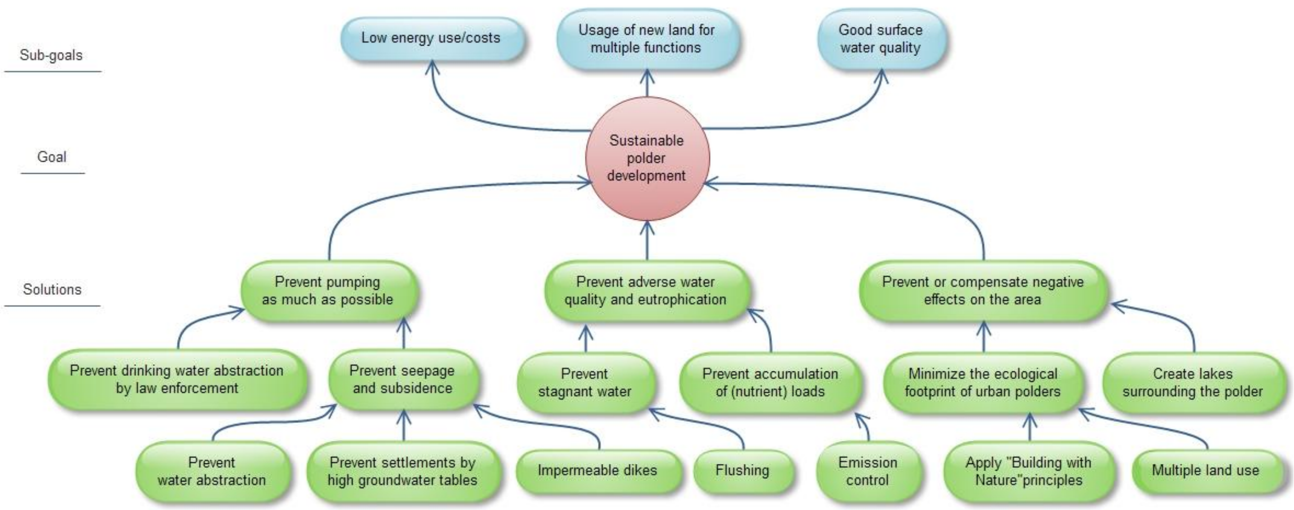


Figure 4.11 Solution tree sustainability

These trees give an overview of the problems and solutions related to sustainability of urban polders. The solutions are elaborated in more detail in the following sections.

4.3.3 Avoid seepage, subsidence and pumping as much as possible

Seepage and subsidence

Seepage is the steady flow of groundwater into the polder. Seepage can enter the polder either via the dike or via the deeper groundwater layers. Seepage results in increased pumping requirements. In coastal environments, the seepage flux introduces higher salinities, which in turn may affect a user function like agriculture.

BioSealing provides opportunities for polder dikes in which seepage takes place. By this, local seepage through the dike decreases, leading to less pumping requirements. Moreover, piping is prevented and failure risks are decreased. The concept functions as follows. In BioSealing, a nutrient-rich mixture is injected near the location of the leak. As the injected nutrients mix with the groundwater, they are automatically transported towards the leak, resulting in an increase of bacterial activity near the leak location. Especially polders in saline areas may profit from the concept, as saline seepage decreases. BioSealing is a measure that is especially applicable during dike maintenance, as different methods of impermeable dike design may be favorable from a financial point of view.

Subsidence is the lowering of the land-surface relative to a datum such as the historical sea level. Subsidence can have various causes, but in the case of polders it is mostly related to the groundwater table, although tectonic movements in certain regions can be significant as well. A distinction is made between peat areas and delta areas.

In peat areas, aeration of the soil leads to the oxidation of its organic components, and this decomposition process may then cause significant land subsidence. This applies especially when ground water levels are periodically adapted to subsidence, in order to maintain desired unsaturated zone depths, exposing more and more peat to oxygen.

According to Fulton (2006), in delta areas where groundwater is abstracted the following process leads to subsidence. When an aquifer system is full of water, the gravel and sands are buoyant. As groundwater levels decline from extraction, there is less buoyancy to support the weight of the gravel and sand that was previously full of water. Additional weight from the gravel and sand creates more downward pressure on clay beds that are between the sand and gravel strata from which water has been extracted. When the water held in the clays can no longer withstand the pressure from the increased weight of the gravel and sands above, the clays are compressed and water is squeezed from them. These clays will never reabsorb the water that has been expelled from them. Permanent subsidence occurs and recharging the ground water to its original levels will not result in the recovery of the original land surface elevations.

Subsidence may lead to increased seepage, which leads to increased pumping requirements. Subsidence in urban polders can be minimized by maintaining high groundwater tables, so that the above-mentioned developments do not take place. Water abstraction from underlying aquifers should be prevented. Nowadays, many subsidence problems are related to human activities. Later in this chapter, an overview will be given of the areas that face serious subsidence problems. Groundwater abstraction (both local abstraction by individuals as well as industrial) should be regulated by law enforcement.

Above, two drivers of subsidence have been addressed, namely natural processes and human activities such as drinking water abstraction. It should be mentioned that subsidence due to natural processes is may be a factor 100 less than subsidence due to human activities (a few millimeters per year compared to up to 15 centimeters per year). Logically, most attention should be paid to the driver of the factor that contributes to the largest subsidence rate. Later in this chapter, how this should be taken into account in the process of polder development.

Reduced pumping

In polder settings, seepage results in more water that has to be pumped out of the polder, which requires energy. In order to reduce pumping as much as possible, a possibility is to combine the drinking water supply with water storage within the polder. The water used to supply the drinking water treatment plant then comes from rain (and when possible seepage), collected in a storage pond (as mentioned, using groundwater leads to further subsidence and should be prevented). The storage area also contributes to increased evaporation. It should however be noted that operating a drinking water treatment plant within the polder is not always possible. In addition, from an economic point of view, maintaining an existing plant outside the polder that supplies via pipe lines will probably be economic favorable. If however a newly constructed plant is required, locating it within the polder will reduce pumping requirements by the amount of consumed drinking water.

4.3.4 Prevention or compensation of negative effects on the area

The "Building with Nature" and "Green Adaptation" concepts

An important challenge in polder development and implementation is to make use of methods that at the same time strengthen the economy and improve the environment, while making optimum use of the available space. Application of "Building with Nature" and "Green Adaptation" are examples of concepts that contribute to a more sustainable polder development.

According to Waterman (2009), the essence of the "Building with Nature" principle is working towards a flexible integration of land-in-sea and of water-in-the-new-land. Hereby it makes use of materials, forces and interactions present in nature. In addition, it takes into account existing and potential nature values, and the bio-geomorphology and geo-hydrology of the coast and seabed.

Figure 4.12 EcoXbloc

Regarding the land reclamation application, the method of Building with Nature should be emphasized, both from the viewpoint of nature as from a viewpoint of cost-effectiveness. Human activities should be incorporated as much as possible in the system of natural cycles. The emphasis is on sustainable development in densely populated coastal and delta areas. The emphasis is no longer on inflexible solid defense works against the sea, like dams and dykes, but instead on flexible soft structures in harmony with the sea, like dunes and beaches. Building with Nature also takes into account the present geomorphology and the historic development of these coastal and delta areas, soil and subsoil characteristics, land subsidence, climate and climate change with all its implications like sea-level rise, higher frequency and intensity of storm surges and rainfall, as well as periods of drought.

An important aspect to be considered when looking into more sustainable polders is the transition from water to land. In this area, many functions can be incorporated. In the first place, as mentioned earlier in this section, safety is to be concerned. However, this can be combined with other functions, such as nature development, recreation, aesthetic values and many others. Considering nature, a soft transition is the best option. It can even be used for treating surface water, by applying wetlands.

Ecology in dike constructions can be stimulated by applying structures that enhance nature development. It is a challenge to design infrastructure in such a way that ecological functions are not damaged, but enhanced. The Dutch concepts of “Rich Revetments” aim at ecologically optimizing traditional coastal defense structures by incorporating ecological needs in the technological design (Hulsman & Maarse, 2010). An example of this development is the application of eco-Xblocs. Due to their shape, the blocks engage each other and are more resistant to waves than usual square blocks. In the cavities and holes of the blocs, sea animals can hide (Rijkswaterstaat, 2009). This type of infrastructure is not that much more expensive than traditional shore protection and creates opportunities for ecology.

Green adaptation, as Building with Nature measure, aims to use ecosystem functions for the benefit of safety against flooding, food and freshwater security and sustainable livelihoods. Increasing population density has led and will lead to an increased pressure on the remaining available space in delta areas.

Regarding future urban polders, the concepts of Building with Nature and Green Adaptation will contribute to a more sustainable development, especially in the transition between water and land. Natural ecosystems and the services they provide will be maintained. Vital ecosystem services, such as water flows and water quality, will be protected and enhanced. Habitats that are important to fisheries and wildlife will be managed. Not only nature, also society benefits from applying these principles (for example fishing industry).

4.3.5 Prevention of adverse water quality

Related to the environmental aspect of sustainability, water quality is an important aspect in urban polder development. Earlier in this chapter, the functions of the water system related to safety issues have been addressed.

Figure 4.13 Urban artificial wetland (source: www.water-in-zicht.nl)

Polders contain drainage canals and presumably storage reservoirs. In order to have healthy ecosystems and a good water quality in the drainage canals and storage reservoirs, it is important to prevent stagnation that leads to adverse water quality (i.a. mosquito breeding and oxygen depletion). A solution to this is to create a constant flow through the ditches by pumping. As a result, sufficient oxygen is available and no mosquito breeding can take place.

Nutrients may pose a problem in urban polders. Sewage leakages may occur, leading to an accumulation of nutrients in the surface water. Another source of nutrients is stormwater runoff. Although emission control is the best way to tackle this problem, also helophyte filters or small artificial wetlands may be applied to treat the contaminated surface water. As can be seen in Figure 4.13, a helophyte filter can perfectly be applied in urban areas such as parks.

Flushing the water system by fresh water from outside the polder is common practice in Dutch polder water systems to avoid water quality problems. In urban polder water systems, flushing by saline water might be considered. In Section 4.3.6 this will further discussed.

4.3.6 Minimize the ecological footprint of urban polders

Minimize the input of water

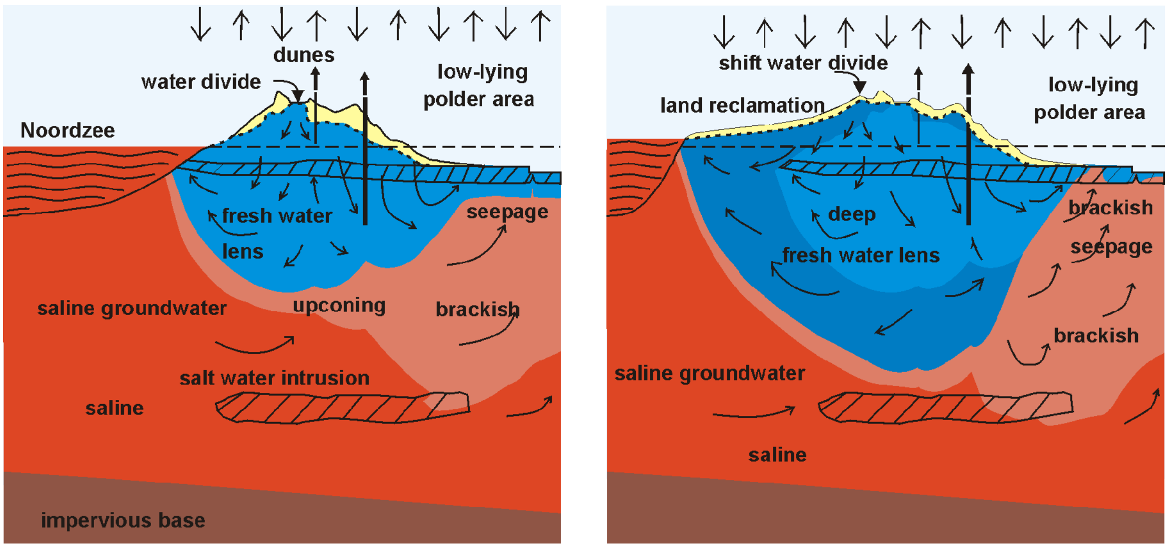


Figure 4.14 Increasing the fresh water lens below the polder

In a situation close to a sea, a fresh water lens is situated below the dunes and part of the polder. Figure 4.14 gives an example of a polder setting near the shore. By creating a larger dune area, the amount of fresh water below the dunes will be increased. Due to the larger and deeper fresh water lens, saline water will be prevented to intrude. This fresh water lens may be beneficial for drinking water production: the input of an external source of water may be decreased resulting in a decrease in pumping requirements. In this way, a balance between input by rain and abstraction for drinking water production has to be created. The applicability of this method depends on the availability of the material required for dune construction. Permeability of this material needs to be

The fresh water lens will contribute to a decrease in saline seepage into the polder. Arguments that are mentioned in literature that advocate prevention of saline water within the polder are the treatment difficulties for drinking water, corrosion of pipes in industries, decrease in crop productivity in agriculture and negative effects on ecology. Considering these arguments as most important ones to avoid saline water, it might be questioned to what extend saline water is a problem in an urban environment.

Saline urban water

As mentioned above, in some situations saline water might not be a problem. Allowing urban polder water systems to be saline affects drinking water treatment. In case the drinking water is distributed from outside the polder, a saline environment is not a problem. Then, saline water accelerates the corrosion process of pipes in industries. If industries are located outside the polder, saline water may be allowed. Agriculture is usually not located within urban areas and will thus not be a problem. Then, ecology may be affected by a higher salinity, but brackish ecology may also provide opportunities for a large variety in flora and fauna.

4.3.7 Multiple land use

Using land for more than one function contributes to a more efficient way of land use. Especially water may be used for multiple functions. Some possibilities of combinations of functions in polder settings are:

- Using storage basins for nature development or freshwater reservoirs.
- Using waterways for recreation.
- Using water bodies to prevent adverse effects on the groundwater in the surrounding area. This situation is applicable in the Netherlands, as mentioned in Chapter 3. Creating new polders may result in a drawdown of the groundwater level in the surrounding area which will be prevented by applying a lake between the new polder and the old land.
- Living near water is an attractive option in the urban environment. By building houses close to waterways, house prices will increase leading to better financing possibilities for polder construction.

4.3.8 Conclusions

All aspects addressed in this section contribute to a more sustainable polder development. Firstly, subsidence and seepage should be avoided as much as possible, either via law enforcement or via physical measures. Subsidence is related to the groundwater level, so high groundwater levels should be maintained. Seepage can be avoided by application of

BioSealing, aspect of the SmartSoils concept. Pumping requirements might reduce by application of a drinking water plant within the polder.

Secondly, principles as “Building with Nature” and “Green Adaptation” contribute to a more sustainable polder development as they take into account natural ecosystems and their services. This prevents the future polders to have negative effects on the surrounding area.

In the third place, adverse water quality should be prevented. Although emission control is the best way to tackle the water quality problems, flushing the water system and applying helophyte filters or artificial wetlands may be applied to treat the contaminated surface water.

In the fourth place, the ecological footprint of polders has to be minimized. This can be realized by minimizing the input of water by creating a fresh water lens below a part of the polder. This concept is applicable in polder settings close to a sea and with sufficient availability of material required for dunes.

4.4 Flexibility

4.4.1 Definition

Flexible polder systems are able to cope with uncertainties and will hence have the capability to adapt to new, different, or changing requirements. In the field of engineering flexible design can be defined as designs that can adapt when external changes occur. This implies that the system is able to respond to potential internal or external changes affecting its value delivery, in timely and cont-effective manner. Thus, flexibility is the ease with which the system can respond to uncertainty in a manner to sustain or increase value delivery.

The elements on which is focused in this research are the effect of climate change and societal changes. These are important and uncertain factors in urban polder development. A problem tree with causes and effects will be given in Figure 4.15. Hereafter, the various aspects that contribute to flexible polder design will be worked out.

4.4.2 Problem and solution tree

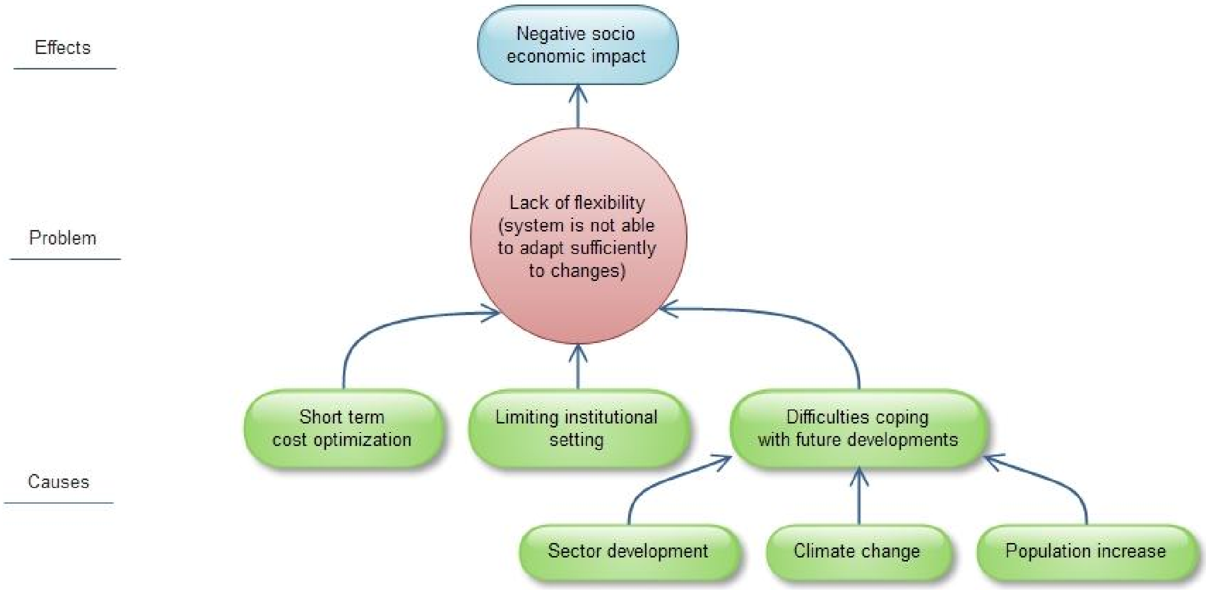


Figure 4.15 Problem tree flexibility

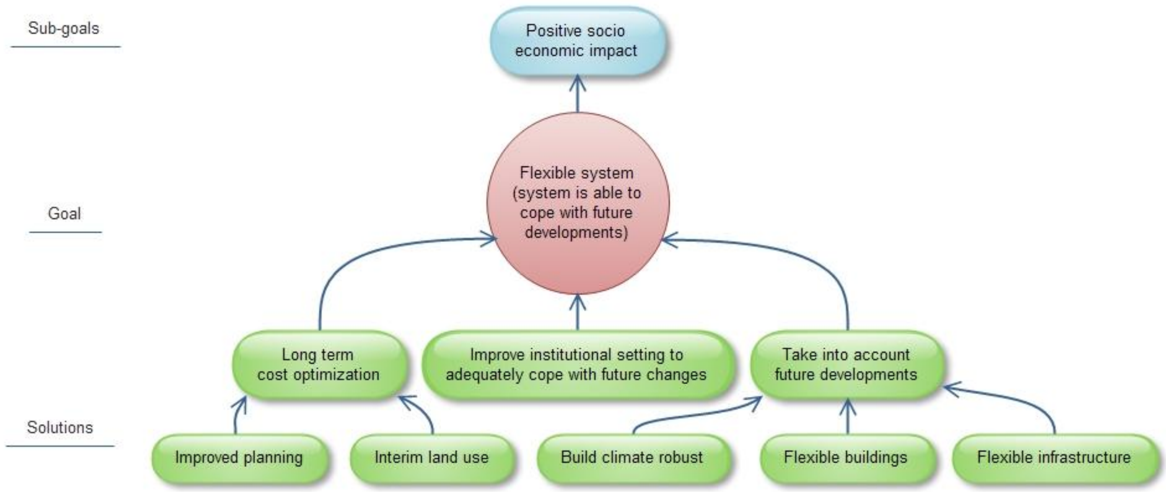


Figure 4.16 Solution tree flexibility

4.4.3 Taking into account future developments

Flexible buildings

Flexible building mainly relates to uncertainty in demand for housing facilities, triggered by population growth. However, up to now buildings are constructed for a lifetime of many decades. During this time, requirements concerning safety, required space, communication facilities, etc. change. In addition, changing societal perspectives on build-up areas might change. Taking these factors into account, flexible design of these areas will lead to a better adaptability in case future develops differently than anticipated.

An example of flexible building is given in Figure 4.17

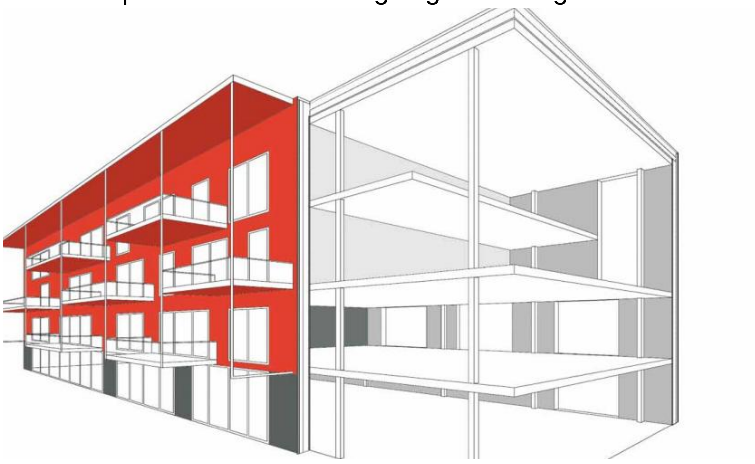


Figure 4.17 Flexible design of residential buildings (source: www.ruukki.com)

The system is meant for multi-story residential buildings. The concept is based on steel frame structures. Partition walls are not load bearing, thus they can be placed freely. The space inside the building can be arranged in many different ways by the user and is easy to change. It is possible to turn smaller apartments into one larger one. Likewise, larger apartments can be divided into smaller ones during the service life. For example, the ground floor can be used as a car park, but can also be furnished as a business area.

Flexible infrastructure

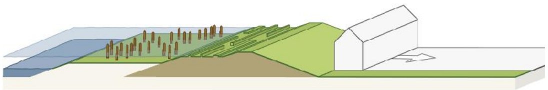


Figure 4.18 Flexible dike design

Flexible infrastructure mainly refers to uncertainty in climate change effects. Linking flood protection to other development issues such as urban (re)development or nature development may be an attractive way to combine more immediate benefits of e.g. urban development with the long-term benefits of flood protection. The following types of infrastructure have the advantage that they are able to be easily adapted in case of changing requirements due to climate change.

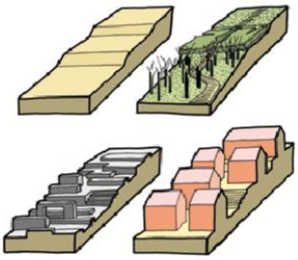


Figure 4.19 Possible wave breaking measures

Figure 4.18 shows a dike with a breakwater on the waterside of the dike. This option is a flexible solution for urban polder protection, since the dike height can be increased without influencing the urban area behind the dike. This type of dike has two major advantages above traditional dikes. Firstly, the dike height can be minimal due to the wave breaking measures. Secondly, the area on the waterside can be constructed in various manners and used for multiple (urban) functions. For example, a park with trees, plants and scrubs can be used as a breakwater. Another possibility is to create an area with terraces, seats and other wave breaking objects. It even is possible to use buildings as breakwaters. It should however be kept in mind that this area is flooded during high water periods (De Urbanisten, 2010). Figure 4.19 gives examples of the mentioned measures.

Figure 4.20 Water Plaza (source: www.rotterdamclimateinitiative.nl)

An example of flexible infrastructure is the water plaza. During dry periods, the plaza will store no water and can be used as a playground. Light or medium rain showers will not cause the plaza to fill up since rainwater is discharged to the sewers. As soon as the rainfall gets heavier, part of the water will reach an overflow point that will, after passing a purification filter, divert it to the plaza. Once the shower is over, the water plaza can be emptied through a pipe that connects to the deepest point in the plaza (Water plazas: playgrounds doubling as water storage).

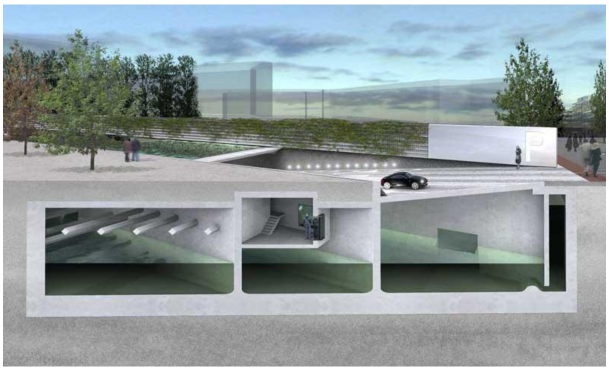


Figure 4.21 Using parking garages for stormwater storage

Another variant of flexible infrastructure can be found in Rotterdam. The idea behind the concept is that the space below the driveways of underground parking garages can be used for stormwater storage (Figure 4.21).

4.4.4 Interim land use

Interim land use is a concept that deals with time and space in a flexible way. It is suitable in areas that have to cope with possible changing functions and climate adaptation. An area gets a useful function, but on the long term it remains available for (often unsure) other functions.

Making temporary use of land in future urban polders will contribute to a more flexible polder concept. For example, part of the polder can be used as a drinking water reservoir that in a couple of years, when the drinking water reservoir is not necessary any more due to other water sources, may be converted to urban area. In section 3.4.2 on the Philippines case, an example of such a development has been given.

4.4.5 Conclusions

The concept of flexibility can be incorporated in urban polder settings in various ways. Flexible building relates to population growth and changes in societal perspectives on build up areas. It can easily respond to changing demands on housing facilities. Then, flexible infrastructure relates to uncertainty in the effects of climate change. In urban polder settings, especially measures related to flooding have to be considered. Flexible infrastructure includes flexible dike design, flexible design of public areas and multiple uses of other facilities. Another example of flexible use space is interim land use. Land can be used for a specific function that may be changed to another function depending on the future needs.

4.5 Recommendations for future polder design

4.5.1 Roadmap for polder development

Figure 4.22 gives the different general steps that have to be taken when implementation of a polder system is considered. Table 4.3 explains the various steps.

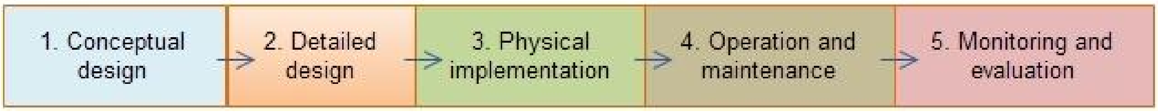


Figure 4.22 Design steps to be taken when implementation of a polder system is considered.

Table 4.3 Description design steps

Phase	Description
1. Conceptual design	The purpose of the conceptual design is, as a first step in the design process, to develop a clear roadmap towards the detailed design study. The conceptual design is a quick look at what is feasible to implement and how much it would cost. This results in an overview of the financial, technical, environmental and operational implications and possibilities of the polder system in the local setting.
2. Detailed design	The conceptual design is followed by the detailed design. In the detailed design, detailed specifications and requirements have to be defined. The detailed design also contains the detailed economic calculations. This leads to an overview of the economic benefits and the construction and O&M costs of the proposed polder. In addition, it takes into account the investment program including the various financing sources (loans and grants, governmental financing, private sector participation, local funds and community participation). An interesting remark on the economic considerations is that polders in almost all cases are economically beneficial, since construction costs are relatively low compared to future benefits. A cost-benefit calculation is in most cases made for a period of 25 to 30 years. The polder however, has a much longer expected lifetime, resulting in a distorted picture of the economic benefits on the long term.
3. Physical implementation	In the implementation phase, the tender documents have to be composed, tendering takes place and construction of the various polder elements are included.
4. Operation and maintenance	This phase consists of the future operation and maintenance of all water management components of the polder.
5. Monitoring and evaluation	In the monitoring and evaluation phase, information from the performance of the different water management components is collected and analyzed to present lessons learned and make adjustments when deemed necessary. In case of failure of specific elements, maintenance is to be scheduled.

4.5.2 Process of physical implementation

In this section, a description is provided of polder development in an existing urban area prone to flooding. Figure 4.23 and Table 4.4 give an overview of the various steps to be taken in the physical implementation phase.

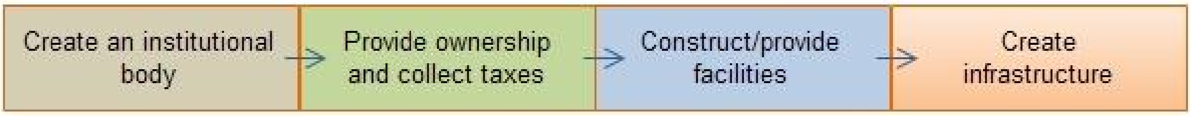


Figure 4.23 Steps in the physical implementation phase

Table 4.4 Description of the steps in the physical design phase

Step	Description
1. Create an institutional body	The most important step in the implementation of the polder is the setup of an institutional body. Since the polder will be constructed for a long time, it requires constant operation and maintenance. The institutional body should be responsible for all physical polder elements, such as maintaining the waterways and taking care of adequate water quality. Moreover, the management should be responsible for fundraising.
2. Provide ownership and collect taxes	In this example, a very important aspect of polder development is to realize local ownership. People get a sense of self-esteem when paying taxes, resulting in investments in their living environment. In order to create dikes (step 4), people that live (in developing countries often illegally) in the space that has to be used for these infrastructure do not receive land ownership and will have to move out.
3. Construct/provide facilities	Facilities such as drinking water supply and electricity lines may have to be adjusted or reconstructed. Drinking water supply is an extremely important aspect in future urban polders, related to subsidence. Due to uncontrolled abstraction of groundwater by individuals and industries, groundwater tables decrease resulting into subsidence. This situation should be avoided in this phase, by constructing a proper distribution network.
4. Create infrastructure	The last step is creating infrastructure. Most important aspects are the dikes, drainage and storage facilities and pumping stations. In addition, transport networks may have to be constructed or upgraded.

As can be seen from the overview, the construction of the infrastructure is preceded by three important steps. In case these steps are omitted or not carried out professionally, various problems will occur. In case a proper institutional body is lacking, the polder will not be able to sustain in the long term. Not collecting taxes may result in lack of financing capacity for creating infrastructure. Self-esteem created by providing ownership is beneficial in order to develop the area further. When facilities are lacking, especially a proper drinking water distribution system, subsidence will take place and will have a negative impact on both the sustainability and safety of the polder.

5 Conclusions

The problem that was addressed in this research was defined as follows:

> *How can the polder concept be optimized to address lack of space issues and increase the safety levels in the delta areas of the world?*

In order to answer this question, the focus in this research was on three issues: safety, sustainability and flexibility. An important conclusion is that safety in future polder developments seems to receive more attention than sustainability. The polder concept in general is for several reasons not very sustainable. Polders require pumping and due to subsidence issues, pumping requirements will even increase. The challenge however is to construct a polder in such a way that it is as sustainable as possible. Moreover, flexibility is getting more important in the future. Flexibility in land use is to be considered in future polders as interests and future conditions may change leading to different functional requirements. Examples of such flexible polder designs that have been discussed in this research are the function change from agriculture to urban land use in the IJsselmeer polders and the considered change from drinking water reservoir to residential use in the Philippines.

From the SWOT analysis, it can be concluded that in order to identify new business opportunities for the Dutch water sector the focus should be on urban polder development. The reason for that, as mentioned in the introduction, is that most economic potential is to be found in urban delta areas. In general, two types of urban polder development can take place. Draining lakes or parts of the seabed and thus creating new land, or protecting existing land against flooding. The second application seems to have greatest business potential in the future. Urban areas that are at an elevation of about sea level are even more prone to flooding due to sea level rise and ongoing subsidence. These areas profit from applying the polder concept in order to prevent to be flooded permanently.

The conclusion drawn from the literature study and case studies is that polders have been developed with various degrees of success. Polder development in the Netherlands has proven to be very beneficial, but the demonstration case for the Philippines shows that polder development in this case may not be implementable. The most important reasons for this are a limiting institutional setting and the lack of financial resources. The institutional shortcoming relates to the fact that polders require a long-term commitment for operation and maintenance. If the institutional setting is not able to support this, polder development will not sustain. During the research, it became clear that three factors are of high importance to the success of polder development. The most important aspect is the institutional setting. Without a proper institutional body, the long-term operation and maintenance requirements can not be met. In the second place, the financial capacity is of importance. Related to the construction and operation and maintenance, sufficient financial resources should be available in order to let the polder sustain. Moreover, the availability of resources is an important factor. In case of sufficient availability of filling material, heightening of the area might be the preferred option from an economic and sustainable point of view. The operation and maintenance requirements of these landfills are less and high safety levels are easier to achieve. Besides these three, other factors may also be important, such as technical know how, experience with water management and socio-cultural aspects.

Another interesting finding that emerged during the research is that polders are in almost all cases economically beneficial, since construction costs are relatively low compared to future benefits. A cost benefit calculation is in most cases made for a period of 25 to 30 years. The polder however, has a much longer expected lifetime, resulting in a distorted picture of the economic benefits on the long term.

After having analyzed the SWOT points and the case studies, the focus was on finding methods for increasing safety, sustainability and flexibility of future polders. Various innovative solutions to problems related to these aspects have been addressed. Different types of flooding (pluvial, fluvial and groundwater) may lead to safety problems. It can be concluded that these safety problems may be solved in various ways, such as the application of the climate dike concept and applying various methods for stormwater storage. An interesting development that may lead to an increase of safety levels by using the polder concept is the protection of utility facilities. By creating polders around utility facilities, local safety increases. In case of high water levels, this concept would prevent disruption of society since basic utilities will remain available during flood periods.

Sustainable polder development may be implemented in future polders by applying a concept such as “Building with Nature”. Important aspects that have to be tackled are seepage and subsidence. Low groundwater tables, caused by either human activities or natural processes, result in subsidence. It should however be mentioned that subsidence due to natural processes may be a factor 100 less than subsidence due to human activities (i.e. a few millimeters per year compared with up to 15 centimeters per year). Concluding, water abstraction should be avoided as much as possible. In case of water abstraction for drinking water purposes, law enforcement should contribute to achieve higher groundwater tables. In the process of future polder development, the installation of a proper drinking water distribution network in an early phase is essential.

Surface water quality within polders can be managed by application of artificial wetlands and flushing the polder with fresh water from outside the polder. However, in urban polder settings water quality may be managed in a completely different way. Saline water systems may be considered. During the research, it was not found that in urban water systems high salt concentrations are a constraint. Vegetation types may be adapted to the saline environment. Flushing the water system with saline water will avoid water quality problems such as blooming of blue-greens and mosquito breeding.

Flexibility relates to changes in land use due to changing interests and conditions. In contrast to safety and sustainability, there is not a general concept available that contributes to a more flexible polder design. Different developments may lead to a more flexible polder design, such as flexible housing and infrastructure. An advantage of the polder concept related to flexibility is the extensibility of polders. Flexible options for financing the complete polder may be available. Another aspect related to flexibility is the uncertainty concerning climate change. The uncertainty is high, which implies that current have to be adaptable to future changes. Finally, flexibility can be introduced by interim land use.

An analysis has been carried out on the sense of urgency of polder development in delta areas. Constructing polders in these areas will lead to various business opportunities for the three sectors (knowledge institutes, business sector, government) within the Netherlands. Knowledge institutes may contribute to the conceptual design studies by addressing e.g. research into sustainability (see Section 3.4.5) and climate proof building. The business sector may profit by the technical implementation of the system. In addition, Dutch engineering firms may support detailed design studies. Governmental institutions may show their excellent experience with organizing the operation and maintenance in polder settings by giving support to institutional aspects, as shown in Section 3.4.4 on the implementation of a polder system in Indonesia.

6 Recommendations

6.1 Recommendations for future research

During the research, it was shown that the institutional setting is often a limiting factor to polder development. Further research is recommended into this topic, in order to get more insight into which settings are suitable and which are not. An optimal institutional model may be developed in which the requirements for successful polder development are taken into account.

Another limiting factor that came up during the research is the local financial capacity. Further research into this topic may provide a better insight into the global settings that are suitable for polder development. Part of this research may consist of finding investment opportunities in areas that need additional safety but are lacking in financial resources. An example that may be thought of is multiple land use for functions that generate additional revenue in order to finance the construction of the polder.

A solution to water quality problems that has been addressed is the application of saline water in urban polders. Arguments that are mentioned in literature that advocate prevention of saline water within the polder are the difficulties of treatment for drinking water, corrosion of pipes in industries, decrease in crop productivity in agriculture and negative effects on ecology. Further research into the adverse effects on the urban environment is required.

Another topic that needs further investigation is the application of a fresh water lens below the polder. It is believed that applying a fresh water lens below (a part of) the polder contributes to an increase of water availability for multiple functions (e.g. avoidance of salinity intrusion and subsidence).

6.2 Recommendations for future business developments

As mentioned in the previous chapter, polder development offers solutions to urban problems as decreased safety against floods due to climate change, sea level rise, subsidence, lack of drainage capacity in urban areas and / or lack of space to implement alternative options (such as local elevations and increased drainage and storage). Utilizing the polder concept in existing urban areas is attractive, especially in areas that face safety problems.

Given the existing Dutch water sector with excellent knowledge on the polder concept there are plenty of opportunities to enhance polder development internationally. This in turn may lead to an increased turnover for the knowledge institutes and business sector that may compensate for the decrease in land and water development related perspectives in the Netherlands. Below, some recommendations for business developments in the different sectors are given.

Knowledge institutes

There are many possibilities to apply innovative concepts addressed in this study in polder settings, such as the “Building with Nature” concept. This concept is applied at the moment in test projects (see e.g. Section 3.4.5 on the New Orleans case study). Other examples of Dutch innovations are SmartSoils and climate dikes (see Section 4.2.3). Some of the specialties that are required during polder development are:

- Dike design
- Water system Design
- Water balance calculations
- Groundwater flow analysis (modeling)
- Slope stability
- Soil settlement analysis
- Soil balance calculations

Business sector

An increase in polder developments abroad will lead to an increased turnover in the business sector. Both engineering companies, designing polders, as the dredging and construction companies, constructing polders, will benefit. The Netherlands' business sector may contribute to provide these specialties.

As mentioned in Chapter 5, the business sector has hardly been involved in polder developments recently. A recommendation that results from the findings during the research relates to the subsidence caused by uncontrolled abstraction of groundwater.

Government

Governmental institutions, such as water boards and municipalities, can be involved in the polder development process by assisting in the set up of an administrative body (as shown in Section 3.4.4 on the Indonesia case study). The Dutch governmental institutions can also demonstrate their excellent experience with organizing the operation and maintenance in polder settings.

Sense of urgency

This section gives an overview of the areas in the world in which the polder concept offers a solution to subsidence-related problems. Table 6.1 (Syvitski et al, 2009) gives the deltas in the world in which subsidence leads to an increased vulnerability to flooding.

Table 6.1 Deltas in which subsidence leads to an increased vulnerability to flooding (Syvitski et al, 2009)

Delta	**Area less than 2m above sea level (km^2)**	**Storm-surge area (km^2)**	**Potential river induced flooded area (km^2)**
Brahmani, India	640	1,100	3,380
Godavari, India	170	660	220
Indus, Pakistan	4,750	3,390	680
Mahandi, India	150	1,480	2,060
Ganges, Bangladesh	6,170	10,500	52,800
Irrawaddy, Myanmar	1,100	15,000	7,600
Magdalena, Colombia	790	1,120	750
Mekong, Vietnam	20,900	9,800	36,750
Mississippi, USA	7,140	13,500	0
Niger, Nigeria	350	1,700	2,570
Tigris, Iraq	9,700	1,730	770
Chao Phraya, Thailand	1,780	800	4,000
Krishna, India	250	840	1,160
Pearl river, China	3,720	1,040	2,600
Tone, Japan	410	220	0
Yangtze, China	7,080	6,700	3,330
Yellow river, China	3,420	1,430	0

Subsidence in these deltas is mainly caused by human activities such as the winning of oil, and gas and the abstraction of water from the delta's underlying sediments. Obviously, not all deltas are suitable for polder development, considering the institutional and financial boundary conditions. An example of a delta that seems promising for polder development is the Mississippi Delta in the USA. The most important boundary conditions are available. An example of a delta in which polder development may be problematic is the Ganges delta in Bangladesh, due to a lack of financial and institutional capacity to let polders sustain.

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Appendices

Appendix A Participants brainstorm session

A List of participants brainstorm session

Company	Participant
Royal Haskoning	Nanco Dolman
Witteveen+Bos	Herman Mondeel
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Grontmij	Enrico Moens
TU Delft	Olivier Hoes
TU Delft	Nick van de Giesen
Deltares	Tjitte Nauta
Deltares	Sonja Karstens
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