Sustainable Societal Infrastructures: A Resilient Approach to Prevent Conflicting Claims of Drinking Water and Other Infrastructures

Kloosterman, Ritsche Anne ; Veeneman, Wijnand; van der Hoek, Jan Peter

DOI
10.3390/su12030785

Publication date
2020

Document Version
Final published version

Published in
Sustainability

sustainability

Article

Sustainable Societal Infrastructures: A Resilient Approach to Prevent Conflicting Claims of Drinking Water and Other Infrastructures

Ritsche Anne Kloosterman [1,*], Wijnand Veeneman [2] and Jan Peter van der Hoek [3]

[1] Vitens, Oude Veerweg 1, 8019 BE Zwolle, The Netherlands
[2] Department of Multi-actor Systems, Section of Policy, Organization, Law and Gaming (POLG), Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands; w.w.veeneman@tudelft.nl
[3] Faculty of Civil Engineering and Geosciences, Technical University of Delft, Mekelweg 5, 2628 CD Delft, The Netherlands; j.p.vanderhoek@tudelft.nl
* Correspondence: rian.kloosterman@vitens.nl

Received: 22 November 2019; Accepted: 14 January 2020; Published: 21 January 2020

Abstract: Societal infrastructures are the lifeblood of societies, and the sustainability of infrastructures is very important. Societal infrastructures can experience conflicting spatial claims with other societal infrastructures, disturbing the sustainable situation. The objective of this paper is to design large infrastructures, with a focus on the Drinking Water Infrastructure (DWI), in a more sustainable way by using the resilience concept. To study this, a case study was done in the Netherlands, where an overlap is present between the DWI and the protection zones, and a new railroad and water safety measures in the river IJssel. The case showed that conflicting infrastructures are inflexible and unable to adapt to change due to several reasons in the governance and in the infrastructure system itself. The case was useful for identifying eight design principles to prevent conflicting claims between large infrastructures.

Keywords: societal infrastructures; sustainability; conflicting spatial claims; design principles; drinking water protection zones; groundwater; IJssel; Zwolle; railroad; governance

1. Introduction

Infrastructures are the lifeblood of societies and their economy, and, consequently, societies rely on sound, functioning infrastructures to provide the expected public value [1–3]. As infrastructures are generally long-term interventions in society and shaping future societies, infrastructures have to be sustainable. The design of sustainable societal infrastructures is challenging. This article focusses on drinking water infrastructures that generally operate on a smaller scale. The literature on drinking water infrastructures is ample, with subjects like the related power relations, the need for local participation, the need for water protection, and the vulnerability to water scarcity, climate change, and other geo-physical changes [4–6]. For drinking water infrastructures, integrated planning is necessary to deliver reliable drinking water and its related public value; delivering on social, environmental, economic, and even mental well-being [7]. In integrated planning, dependencies with other societal infrastructures are always present, from polluted waterways to cohabited underground space. However, what are the elements for integrated planning when dependencies are present with other societal infrastructures that mainly operate at a larger scale? How do we link the local ties of Drinking Water Infrastructures to the wider ties of large-scale infrastructures? What complexities occur, and how can they be managed in a sustainable way?

Societal infrastructures have to be considered as Social Technical Systems, with actor behavior explaining the performance as much as the technical design. Moreover, the Drinking Water Infrastructure (DWI) system is a System of Systems (SoS) operating in both the Social Technical Systems (STS) and in the Social Ecological System (SES), as the water resources and space used for DWI, including zones used to protect the quality of the extracted water, are part of the SES [8–10]. The interface between these two systems is complex due to the different characteristics and sustainability demands of STS and SES systems.

Using and protecting water resources for DWI systems requires a lot of space, which often causes conflicting claims on the space from other infrastructures [9,11–15]. The objective of this paper is to learn more about this type of conflicting claim and to develop design principles in order to be able to design societal infrastructures in a more sustainable way without this type of conflicts.

Especially in urban areas, the space available is becoming more and more crowded, making it important to prevent or reduce the impact of conflicting claims of infrastructures. If infrastructures have a claim on the same space, costly measures have to be taken to guarantee the functioning of the infrastructures [16].

Systems are less affected by conflicting claims if they have the resilience to adsorb disturbances and are capable of re-organizing while undergoing changes [17–20]. The resilience concept may be used to develop design principles. The research question concerns how the resilience concept can be used to develop design principles to prevent conflicting claims of societal infrastructures and achieve a more sustainable situation.

2. Approach and Resilience Concept

2.1. Approach

In this sub-section, the materials and methods of this research are described.

The objective of this research is to develop design principles to prevent conflicting claims of large societal infrastructures. To develop these design principles, a case study was carried out in the city Zwolle, in the Netherlands, where a drinking water production plant with protection zones is located. With regard to infrastructures, an overlap exists between the drinking water protection zone and a new railroad in the protection zone (conflict 1), and also between the drinking water protection zone and the river IJssel and water safety improvement measures (conflict 2).

First, in Section 2.1, the resilience concept is studied in more detail to determine how this concept can be used in this specific case to develop design principles. Resilience is a way of coping with change [21] and can be used to address the dynamics and developments of complex systems [17].

The resilience perspective is from ecology, where it is defined as the capacity to persist within one domain in a world with alternate domains of attraction with non-linear dynamics [8]. Systems can retain the same function, structure, identity, and feedbacks if they have the resilience to adsorb disturbance and re-organize while undergoing changes in their adaptive capacity and other capacities like human actions [8,18].

Resilience is appropriate for disruptions with a high impact and a low frequency [22]. This makes resilience an interesting concept for studying the way that a DWI system can minimize the impact of conflicts between infrastructures due to changes.

Resilience is a broad concept, is highly contextual, and is dependent on the environment, the disruptive event, and the architecture of the system [22]. Quantitative design approaches are missing, and that is the reason that principles and heuristics have been developed, including the so-called Resilience Enhancing Design Principles (REDP) [22–26]. DWI systems work at the interface of two systems (SES and STS). At that interface, a choice has to be made between the REDP of STS and SES because, in the interface, both are valid. In this research, the REDP of a SES, which are structured along two axes and are used (Table 1) because the conflict of societal infrastructures (STS) is a conflict on space. This is an important subject of SES. Another reason is that societal infrastructures are mostly seen as an STS, and studying STS infrastructures from an SES perspective is a new and challenging perspective.

In Section 3 the case is described with a focus on the two conflicts. What were the causes of these conflicts and how were they handled?

In Section 4, the case is analyzed with the objective of finding design principles. In the second part of this section, the applied methodology to define design principles is evaluated on three criteria: reliability, validity, and generalization, as described by Morse [27] and Maxwell and Chmiel [28]:

- Reliability: are the same design principles obtained if the study was repeated?
- Validity: are the conclusions recognizable by the stakeholders? The discussion is done by evaluating the acceptance of the results by the stakeholders.
- Generalization: are the design principles applicable for other cases with conflicting infrastructures?

In the last section, the conclusions and recommendations are presented.

2.2. Resilient Enhancing Design Principles in Social Ecological Systems (SES)

In this sub-section, the Resilient Enhancing Design Principles and the way they can be categorized are described.

Resilient Enhancing Design Principles (REDP) in SES are summarized by Biggs [25] in seven generic resilience principles for enhancing social-ecological systems in order to deliver the desired services. These seven principles can be organized along two axes, one axis focusing on the analysis (of the architecture) of the system or the governance of the system and the other axis on system structure or system dynamics (Table 1) [17,29]).

Table 1. Seven Resilient Enhancing Design Principles (REDP) of a Social Ecological System (SES).

	System Structure	System Dynamics
Governance of the SES	• Enhance polycentric governance • Broaden participation	• Encourage learning & experimentation • Foster complex systems understanding
Analysis (Architecture) of the SES	• Maintain functional & response diversity • Manage connectivity	• Manage slow variables & feedbacks

3. Case Study Zwolle

In this chapter the case is described with a focus on the two conflicts. What were the causes of these conflicts and how were they handled?

During the industrial revolution, a lot of people moved to the city to find a job, which caused hygiene problems because more and more people were living on the "same" surface. Faeces contaminated the water that was used as drinking water, and the first outbreak of a cholera epidemic was in 1830 in the London area. Thousands of people died and collective sanitation was needed [30]. In the Netherlands, local communities were responsible for the sanitation. Amsterdam was the first community to take on this responsibility, establishing a water company in 1853. Zwolle, the research area of this case study, followed in 1893 [30]. Zwolle was founded in the Middle Ages on a sand ridge between two rivers: the IJssel (one of the outlets of the river Rhine) and the Vecht. South of the Ijssel, a very big sand ridge emerged during the last ice age: the Veluwe.

Sand ridges are very attractive for extracting groundwater for drinking water supply. The chemical reactiveness of the sand ridge is low, which makes the water very easy to purify. Even nowadays water extracted in some locations on the Veluwe does not need any treatment [31]. This was the reason that the community of Zwolle started, in 1911, a groundwater extraction on the Veluwe for the drinking water supply of Zwolle. This location was called "Zwolse Bos", which means wood of Zwolle, because on the location trees were also planted for wood production. A pipeline under the IJssel was made to transport the water to the city of Zwolle. During World War II, bridges over the river IJssel were bombed frequently. The vulnerability of pipes—to bombing—in the Ijssel was the reason that, after the war, the community of Zwolle decided to close the extraction on the Veluwe and to move to a place close to the city, called Engelse Werk (Figure 1). In Engelse Werk, a park was landscaped in the English style, with a lot of ponds and canals.

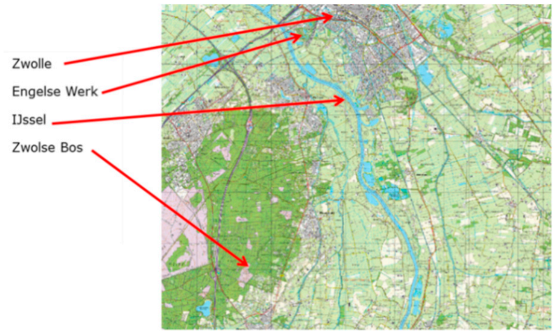

Figure 1. Zwolle and environment.

The Dutch national Research Institute for Drinking Water (RID) (Rijks Instituut voor Drinkwatervoorziening), which was established to help the communities with knowledge, wrote in 1959: The subsoil at Engelse Werk can be seen as a sand layer, with a thickness of 150 m, with very good water permeability. Above this sand layer is a layer with low water permeability that consists of clay and peat [32]. In 1960, the Water Company received a permit to extract 5 million m^3/year.

A few years later, customers started complaining about the taste of the drinking water. Employees of the Water Company found that the bad taste was found in some of the wells and they cleaned the wells carefully. It took several decades of research and discussion to act on these complaints. In 1986, the drinking water treatment facility was extended with activated carbon to eliminate the taste problems.

The opinion of the national government on the use of groundwater for drinking water changed in time (Table 2) [33–41].

Table 2. Policy of the government on groundwater (a Common Pool Resource: CPR).

Period	Time	Characteristic of the Government of CPR Groundwater
1	1853–1984	High priority for drinking water use
2	1984–2000	Balance between use and impact on the environment (drought); an integral approach
3	2000–now	More anticipating on future uncertainties and more using of natural (space) possibilities beside techniques
4	2009–now	A complete decentralized integrated approach

A new extraction permit for 8 million m^3/year was given by the ministry in 1970. The permit had two conditions: regularly measuring some of the monitoring wells and the level of the ponds in the park Engelse Werk. If the level of the ponds became too low, the water company had the obligation to take measurements.

In 1977, the province wanted to protect the quality of groundwater by defining protection zones, where the groundwater had the same or a lower travel time, before it was extracted in accordance with the environmental rules in those zones [42]. There were different zones defined to guarantee the biological quality (first zone), the chemical quality (second zone), and the, from a quality risks viewpoint, undesired combinations of potential pollutant activities, or functions (third zone). For the clarity of this article, these different zones are not further distinguished, as they all have comparable impacts on other infrastructures.

A report of the National Geological Institute in 1978 changed the ideas of the subsoil dramatically, stating that: "It should be considered that the subsoil of the Engelse Werk is a glacial disturbed area (part of the Veluwe) and understanding of this subsoil requires a very dense amount of bore holes" [43]. A few years later, the drinking water company presented the results of chloride measurements in an internal report and concluded: "the extracted groundwater contains much more infiltrated water of the river IJssel then we ever thought before" [44]. The amount of infiltrated surface water was about 2/3 of the total extracted water amount, with an average travel time of four years. This was a mind shift, because now the quality threats came from two sides: not only polluted groundwater from the city (area around the railway station) but also pollutions in the IJssel river. A few years later this became a reality because, in 1987, a pollutant of the river water, Bentazon, was found in the extracted water [45].

Additionally, during that time, the impact of the warning from the National Geologic Institute became more concrete. Several geo-physical investigations and drillings made clear that tilted clay layers in the shallow sand layer disturbed the groundwater pattern dramatically [46,47].

For the expected increasing water demand the Ministry of Infrastructure and Water management gave, in 1986, a new permit for the groundwater extraction of Engelse Werk of 10 million m^3/year, with comparable conditions to the permit of 1970. The permit also contained the permission to extract 2 million m^3/year in a deeper sand layer. The impact of an extraction under a very thick and nearly impermeable layer is spread over a large area and is in the Zwolle area that is neglectable compared to the bigger extraction in the shallower sand layer. This is the reason that the extraction in the deep layer is not treated further in this article. As a result of the new permit, comparable with earlier permits, the extraction, treatment, and pumping installation were extended.

Based on this new permit and new information on the subsoil and the groundwater flow pattern, the groundwater protection zones and rules of the province were sharpened in 1986 and 1989. In 1999, in an extraction well located close to the railway station, vinyl chloride (a pollutant with an industrial background) was found. Groundwater pollution, caused by industrial activities around the railway station, was, from that moment on, an important issue in the groundwater protection activities. An independent engineering consultant calculated how the protection zones could be changed if the wells were moved away from to railway station to the IJssel [48].

To secure the future drinking water demand, the drinking water company applied, in 1990, for a new permit for an extraction of 12 million m^3/year. The production of drinking water increased in time (Figure 2).

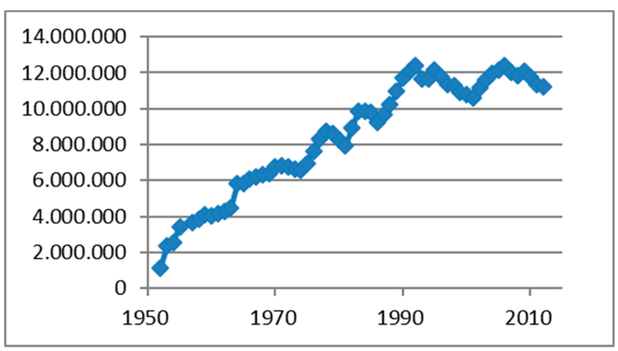

Figure 2. Groundwater extraction at the Engelse Werk production location.

Another threat for the drinking water extraction was the decision of the Ministry of Infrastructure and Water Management to build a new railroad (the Hanze railroad) to connect the western and northern part of the Netherlands [49]. The central connection point was the railway station of Zwolle, and years later it turned out that the new railway—and other installations that were necessary because Zwolle became a very important railway connection point—was planned next to the extraction wells of Engelse Werk. These activities are forbidden in the protection zones, as described in the rules of the province. This led to many administrative and legal efforts to integrate these activities.

During the same period, the drinking water company published a long-term plan [50] with the strategy for Engelse Werk: "Maintaining and maximum use of the licensed capacity of English Work and solving the quality problems, especially hardness". The background of this strategy was based on the expectation that the expected growth of the water demand would not occur and that developing new extraction locations was not necessary anymore. It was better to optimize the existing locations via a sustainable integration with other functions or via reliable connections (with pipes) to other production locations to guarantee the drinking water supply at all times. This was a mind shift, as earlier plans emphasized the need to develop new extraction locations.

This ambition for Engelse Werk did not change the long-term infrastructure plans that were published later, but the way to achieve this changed. In 1997 and 1999 the focus was on the awareness of the negative impact and the possibility of eliminating and preventing the negative impact [51,52]. The next plan was published after a merger between water companies, and the focus was not only on solving negative impact problems but also on the integration of the two companies [53]. The next plan after, another merger, focused more on the following (asset management) business approach: trying to find a balance between acceptable costs, acceptable risks, and desired performance [31] instead of the engineering approach of achieving high performance by reducing risks for acceptable costs.

In 2003, an agreement was established between the industries responsible for the groundwater pollution, the municipality of Zwolle, the province and the water company. The content of this agreement was as follows: "drinking water company removes before 2010 a part of the extraction. After this move the groundwater protection zones are located outside the station area making new activities possible without limitations caused by the groundwater protection rules".

The expectation of the drinking water company was that the current treatment was sufficient in the new situation [48]. This assumption later proved to be partly incorrect. In the new situation, the wells are located close to the IJssel and the large percentage of IJsselwater (up to 90%) and the short travel time of the infiltrated water through the soil, meaning that the extracted water probably would be no longer anaerobic, but aerobic. There was also a need to lower the hardness of the water. The combination of these two aspects made the water company decide to build extra treatment units and reconstruct current treatment processes [31]. These modifications were very costly, and the costs became ten times higher than those estimated in 2003.

In 2004, risk analyzes were made by independent consultants. The objective of the risk analysis made by Arcadis was to calculate the risks and mitigation measures of the new Hanze railroad for groundwater pollution according the protection rules of the province [54]. TAUW [55] compared different locations for the extraction wells. It was difficult to define the optimal location, as all locations had advantages and disadvantages. In an agreement with the railway manager, some wells close to the railway had to be replaced and groundwater protection measures had to be taken.

The drinking water company made an internal study a reconsideration of the agreement of 2003, in which parties agreed to replace a part of the extraction [56]. In this review, the drinking water company compared different alternatives to secure the drinking water supply of Zwolle and the surroundings. Some of the alternatives were located far away from Zwolle, like a new river bank infiltration plant and the use of other existing extractions. It turned out that differences in costs were not a distinctive criterion, mainly due to different and often unknown life times of the different assets. Uncertainties regarding possible problems by developing new locations increased this complexity. The conclusion of this reconsideration was to continue the replacement, motivated by the importance of keeping to the agreement. To secure the desired amount of 12 million m^3/year in acceptable protection zones, it was necessary to develop new unorthodox technical solutions to extract groundwater. These different solutions are not discussed in this paper but they illustrate the very limited solution space. In addition to the technical difficulties, it was a challenge to integrate the new extraction wells in a rural environment. The legally required environmental assessment was realized in 2006 [57].

The objective of the environmental assessment was to realize an extraction of 12 million m^3/year without risky activities in the protection zones, which was in line with the agreement of 2003 and the agreement about the Hanze railway. To realize this objective and to guarantee a sustainable solution, a partnership 'IJsselzone Zwolle' was established with the community of Zwolle, the drinking water company Vitens, and all public and private partners who were involved. The objectives of the partnership 'IJsselzone Zwolle' were designed to realize a sustainable situation in this area by realizing [57]:

- At least one economically stable farm and several large farms focused on sustainable agriculture and nature management;
- The European, national, and provincial nature ambitions for this area;
- An increase in the recreation possibilities;
- Maintenance of the green and quiet character;
- A water management focused on safety (for river floodings), water quantity, and water quality;
- A water extraction in this area to fulfil the abovementioned objective of the drinking water company.

As most of the desired results were realized, this partnership can be seen as successful.

The National Program "space for the river" [33] made it, in 2003, necessary to build a secondary channel in the floodplain along the river IJssel close to Engelse Werk. The protection of groundwater for drinking water applications had an impact on the way this work was done. Later, it also became clear that a lowering of the river level was necessary. The impact of the planned lowering of the level of the IJssel by 0.1 m on the groundwater streaming pattern was significant and disturbed the delicate integration process in the partnership IJsselzone Zwolle. This meant that the planned lowering was cancelled and replaced by other measures.

The extraction, in combination with the groundwater protection zones at Engelse Werk, has a critical size, that is, there is no or insufficient room to absorb changes in activities. In addition to the problems mentioned above, households and enterprises are confronted with extra costs to protect the groundwater, and the extraction causes droughts, which impact valuable trees and other nature. The protection zone also has an economic impact in a city like Zwolle, as enterprises have to deal with requirements to protect the groundwater, which can lead to the decision to go to another place.

4. Results

4.1. Analysis of the Case and Identification of Design Principles

In this sub-section, the case is analyzed by using the two axes that are derived in Section 2.

Based on the categorization in Table 1, four combinations are possible by using the two axes. The case is analyzed for each combination of events, incidents, and occasions that impact on the two spatial conflicts: the conflict between the DWI and the RailWay (RW), and the conflict between the DWI and the river or Water Way (WW), with the main players being the community, the DWI, enterprises, and local stakeholders.

The four combinations are summarized in Table 3.

Table 3. Analysis of the case with use of the governance/analysis dimension and the system structure/system dynamics dimension.

	System Structure	System Dynamics
Governance of the SES	All issues, incidents and occasions with respect to participation of different stakeholders and all static governance aspects	All issues, incidents and occasions with respect to learning and understanding of the system
Analysis (Architecture) of the SES	All issues, incidents and occasions with respect to diversity and connectivity of the system	All issues, incidents and occasions with respect to slow variables and feed backs of the system

Based on the categorization in Table 3, all the issues, incidents, and occasions are identified and summarized in Figure 3. The first column describes these issues, incidents and occasions. Columns two and three describe whether they are applicable in the two conflicts. In column four, an explanation is given, while in the last column the design principles that can be derived are presented.

Governance: system structure				
Events, incidents and occasions	is it applicable in:		Explanation	Design principles that can be formulated
	conflict 1: railway (RW) and DWI	conflict 2: waterway (WW) and DWI		
flexibility of company in working area to find new solutions	DWI: limited RW: no	DWI: limited WW: some	changes in DWI architecture depends on the scale of the DWI systems what is managed by the company: Optimization on a higher scale is complex or sometimes impossible; The RW has almost no flexibility in the design as the lay out is planned on national level, while the WW can develop different solutions: the objectives are determined on national level and not the exact design, what is worked out on local/regional scale; on local scale some flexibility is possible.	enhance flexibility in (sub)system scale to find solutions
flexibility in protection zones of DWI	very limited	very limited	protection zones are located in a crowded and sensitive (for pollutions) area, with no opportunities for change	enhance flexibility in the spatial claim of the infrastructures enhance flexibility in the protection zones and protection regime of DWI systems
not aligning governance; governance on different levels and on different moments in time;	DWI and RW: important issue	DWI and WW: important issue	national infrastructure decisions with impact on local level: A new railroad, changes in the river management; conflicting claims due to different decisions in time (Decision about lay out of DWI system started after World War II, while the RW and WW plans are much younger). On local scale the governance is easier to align, although there always are some important attention points.	enhance alignment of the planning of infrastructures on different governance scale levels and in time
possibility for partnerships and agreements	DWI and RW: not done	DWI and WW: some possibilities	the partnership 'IJsselzone Zwolle' helped to realize solutions on local scale and to find solutions for the WW within the borders of the national program	stimulate and broaden participation in the planning phase

Governance: system dynamics				
Events, incidents and occasions	is it applicable in:		Explanation	Design principles that can be formulated
	conflict 1: railway (RW) and DWI	conflict 2: waterway (WW) and DWI		
preventing mind shifts	issue	issue	preventing mind shifts by understanding the system and possible changes helps to manage the system more effective	stimulate learning and understanding of the infrastructure system(s) and interactions between the infrastructure (systems)

Analyse the system: system structure				
Events, incidents and occasions	is it applicable in:		Explanation	Design principles that can be formulated
	conflict 1: railway (RW) and DWI	conflict 2: waterway (WW) and DWI		
possibility to adapt to change in current lay-out of infrastructure	DWI: no RW: no	DWI: no WW: some	differences are related to design decisions and the life cycle phase (DW: operating, RW: design on national scale; WW: objectives formulted on national scale, but design on regional/local scale). On	stimulate functional en response diversity in the systems

Analyse the system: system dynamics				
Events, incidents and occasions	is it applicable in:		Explanation	Design principles that can be formulated
	conflict 1: railway (RW) and DWI	conflict 2: waterway (WW) and DWI		
long life time and high capital costs of the infrastructure assets	DWI and RW: important issue	DWI and WW: important issue	changes in the architecture of (DWI and other) infrastructures are very difficult to realize due to high costs and the interdependency of the assets	be aware and manage slow variables like: long life time and high costs of the infrastructures, interdependencies between infrastructures, new technologies, new system knowledge and changing ideas, opinions and policies of stakeholders, disruptive events
new geo-physical knowledge: new information and ideas about subsoil, (ground)water flow, water quality etc.	not an issue	not an issue	minds shifts can have impact on the current lay-out of the infrastructure and on the plans and ideas	
changing technical possibilities (new monitoring, new analyse and water treatment techniques, cheaper materials and equipment etc.)	not an issue	not an issue		
changing ideas and expectations of stakeholders (costs, tariffs and risk information and acceptance, desired performance)	not an issue	issue		
extreme events like wars	had impact on the current lay-out of the DWI system			

Figure 3. Spatial conflicts between the Drinking Water Infrastructure (DWI) and the railway infrastructure, and between the DWI and the waterway infrastructure in the case of Zwolle, and design principles that can be formulated.

4.2. Discussion

In this sub-section, the design principles of Figure 3 are discussed on reliability, validity, and generalization.

In the case study, the objective was to identify design principles to design infrastructures in a more sustainable way by learning from two conflicting claims of three specific infrastructures. As can be seen in Figure 3, there are some similarities and differences between the two conflicts. Based on these, eight design principles were derived (last column of Figure 3), which have to do with:

(A) Understanding the System

The case shows changes in knowledge, technology, and the opinions of stakeholders. Infrastructure systems and the interdependencies of these systems are very complex, and understanding the system on different levels is important to prevent increasing complexity due to changes in the system(s).

(B) Handling the Different Time Scales of Infrastructures

Infrastructures have long, different, and mainly not synchronic lifecycles. The case shows that this is an important cause for conflicting claims. Infrastructure managers should involve each other in the planning phase. This can be done be making infrastructure impact analyses of infrastructure plans. If the planning phases are more or less in the same time period, a co creation processes, like the partnership 'IJsselzone Zwolle' is recommended.

(C) Creating Response Diversity by Using Flexibility

(1) Flexibility in the protection zones.

This can be done by designing protection zones based on the real risks and with enough space to adapt to changes. Another strategy is to have the possibility to take measures to reduce the risks of new activities in the protection zones. A requirement to achieving all this is a good understanding of the relation between new activities and the risks for drinking water.

(2) Flexibility in the drinking water infrastructure can guarantee the services in another way. Alternatives that can be realized in a relative short period (about 1 year) are missing in the case. Connections between water resources (with flexibility in the extracted amount of water) or connections between water supply areas, to be able to serve these areas in more than one way, are recommended to increase the response diversity.

(3) Flexible lay-out of the wells of the water resources.

The case shows that not all wells are affected by the conflicting claims. Flexibility in the layout of wells, by spreading and making or reserving space for extra wells gives response diversity.

These design principles (Figure 3) are discussed based on reliability, validity, and generalization.

Reliability:

If the study was repeated, would the same design principles remain? The steps that were followed with an impact on the result are: 1) applying the resilience concept, 2) describing the case, 3) analyzing the case, and 4) describing the design principles. These four steps are discussed based on reliability:

(1) Applying the resilience concept. Resilience turned out to be useful for analyzing the case. Other researchers may use other concepts that can give additional design principles. It is recommended to apply other concepts to find possible additional design principles.
(2) Describing the case. The description and information that is found in the desk study depends on the researcher. To prevent missing relevant information, three infrastructure managers (DWI, railway, and waterway) were interviewed and asked to give all the relevant information.
(3) Analyzing the case. Using the four combinations helped to identify different design principles, but the results are dependent on the researcher. A double analyze check was done to prevent missing any design principles.

(4) Describing design principles. The description is the result of the previous three steps. Other researchers may formulate the design principles differently, but it can be expected that the content is more or less the same as this—a direct consequence of the previous steps.

Validity:

In the Netherlands, six large infrastructures work together in a cooperation called NGinfra (www.nginfra.nl). The three infrastructures who are involved in the conflict are members of NGinfra. In a meeting of a technical committee of NGinfra with representatives of the three specific infrastructures, the design principles were presented, recognized, and used as building blocks to plan new projects.

Generalization:

Spatial conflicts between large infrastructures are seen regularly and it can be expected that the design principles are applicable to all sorts of spatial conflicts between large infrastructures. However, this is not tested yet. It is recommended to study other cases with spatial conflicts between infrastructures and evaluate the use of the eight design principles.

5. Conclusions and Recommendations

In this section, conclusions and recommendations are given based on the research question.

The aim of this study was to develop design principles to prevent conflicting claims of large societal infrastructures, and the research question concerns how the resilience concept can be used to realize this. The literature review showed that resilience is a broad concept and highly context dependent. As DWI systems operate in the STS and SES, and the interest is on spatial conflicts, the resilience enhancing design principles of the SES are used. The REDPs and the categorization of the REDPs of the SES turned out to be applicable in a reliable and valid way to analyze the case and to develop eight design principles. The eight design principles reflect the attention fields of the REDPs. What would the design principles look like if the REDPs of, for example, the STS were used or concepts other than resilience were used? It is recommended to investigate whether other concepts would give additional design principles.

A research method case was used, which turned out to be a good method for developing design principles. Whether the generalization of the results of a case study is possible is always difficult to indicate. As spatial conflicts between large infrastructures are often seen and the results were recognized by the stakeholders, it is expected that the eight design principles are applicable in other spatial conflicts between large infrastructures, but this is not validated. It is recommended to apply the design principles in other cases to evaluate the possibility of generalizing the design principles in other spatial conflicts between infrastructures.

Author Contributions: R.A.K. designed and performed the research and analyzed the data and wrote the paper. W.V. supervised the research and approved the final manuscript. J.P.v.d.H. supervised the research, assisted in writing the article and approved the final manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Koppenjan, J.; Charles, M.; Ryan, N. Managing Competing Public Values in Public Infrastructure Projects. *Public Money Manag.* **2008**, *28*, 131–134.
2. Van der Wal, Z.; de Graaf, G.; & Lawton, A. Competing Values in Public Management. *Public Manag. Rev.* **2011**, *13*, 331–341.
3. Steenhuisen, B. *Competing Public Values; Coping Strategies in Heavily Regulated Utility Industries*; Delft University of Technology: Delft, the Netherlands, 2009.

4. Sekercioglu, M.; White, J.; Shrubsole, D.; Baxter, J. Towards a Sustainable Small Non-Community Drinking Water System in Ontario: Owners' Risk Awareness and Perceptions to Water Safety. *J. Sustain. Dev.* **2018**, doi:10.5539/jsd.v11n3p71.
5. Vongmany, O.; Watanabe, K.N.; Mizunoya, T.; Kawase, M.; Kikuchi, A.; Yabar, H.; Higano, Y.; Sombounsack, N.; Phounpakon, O. Sustainable Water Management under Variable Rainfall Conditions in River Communities of Champhone District, Savannakhet Province, Lao PDR. *J. Sustain. Dev.* **2018**, *11*, doi:10.5539/jsd.v11n3p108.
6. Kilonzo, R.D.; George, V. Sustainability of Community Based Water Projects: Dynamics of Actors' Power Relations. *J. Sustain. Dev.* **2017**, doi:10.5539/jsd.v10n6p79.
7. Beam, J.; Nawari, N.O.; Tilson, B. Mental Health & Resiliency: Designing Participatory Nature Dependent Environments and Communities for a Sustainable Future. *J. Sustain. Dev.* **2018**, doi:10.5539/jsd.v11n3p234.
8. Folke, C. Resilience: The emerge of a perspective for social-ecological system analysis. *Glob. Environ. Chang.* **2006**, *16*, 253–267.
9. Ostrom, E.; Gardner, R.; Walker, J. *Rules, Games and Common-Pool Resources;* The University of Michigan Press: Ann Arbor, MI, USA, 1994.
10. Makame, M.; Kangalawe, R. Water Security and Local People Sensitivity to Climate Variability and Change Among Coastal Communities in Zanzibar. *J. Sustain. Dev.* **2018**, doi:10.5539/jsd.v11n3p23.
11. Dietz, T.; Ostrom, E.; Stern, P.C. The struggle to Govern the Commons. *Science* **2003**, *302*, 1907–1912.
12. Gleick, P. Water and conflict: Fresh water resources and international security. *Int. Secur.* **1993**, *18*, 79–112.
13. Olsson, G. *Water and Energy: Threats and Opportunities*; IWA publishing: London, UK, 2015.
14. Ostrom, E. *Governing the Commons; the Evolution of Institutions for Collective Action (Canto Classics)*; Cambridge University Press: Cambridge, UK, 2015.
15. Ostrom, E. A diagnostic approach for going beyond panaceas. *Proc. Natl. Acad. Sci. USA* **2007**, *104*, 15181–15187.
16. Vitens. *Veerkrachtig Vooruit*; Vitens: Zwolle, The Netherlands, 2016.
17. Folke, C.; Carpenter, S.; Walker, B.; Scheffer, M.; Chapin, T.; Rockström, J. Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecol. Soc.* **2010**, *15*, 20.
18. Anderies, J.; Janssen, M.; Ostrom, E. A framework to Analyze the Robustness of Social-ecological Systems from an institutional perspective. *Ecol. Soc.* **2004**, *9*, 18.
19. Künneke, R.; Finger, M. The governance of infrastructures as common pool resources. In Proceedings of the Fourth Workshop on the Workshop (WOW4), Bloomington, IN, USA, 2–7 June 2009.
20. Goldthau, A. Rethinking the governance of energy infrastructure; Scale, decentralization and polycentrism. *Energy Res. Soc. Sci.* **2014**, *1*, 134–140.
21. Walker, G.; Holling, C.; Carpenter, S.; Kinzig, A. Resilience adaptability and transformability in social-ecological systems. *Ecol. Soc.* **2004**, *9*, 5.
22. Uday, P.; Marais, K. Designing Resilient Systems-of-Systems: A survey of Metrics, Methods and Challenges. *Syst. Eng.* **2015**, doi:10.1002/sys.21325
23. Woods, D.D. Chapter 2: Essential Characteristics of Resilience. In *Resilience Engineering*; Ashgate Publishing Ltd.: Farnham, UK, 2012.
24. Jackson, S.; Ferris, T. Resilience Principles for engineered systems. *Syst. Eng.* **2012**, *16*, 152–164.
25. Biggs, R.; Schluter, M.; Schoon, M. *Principles for Building Resilience; Sustaining Ecosystems Services in Social-Ecological Systems;* Cambridge University Press: Cambridge, UK, 2015.
26. Biggs, R.; Schluter, M.; Biggs, D.; Bohensky, E.L.; BurnSilver, S.; Cundill, G.; Dakos, V.; Daw, T.M.; Evans, L.S.; West, P.C.; et al. Toward Principles for Enhancing the Resilience of Ecosystem Services. *Annu. Rev. Environ. Resour.* **2012**, *37*, 421–448.
27. Morse, J. Critical Analysis of Strategies for Determining Rigor in Qualitative Inquiry. *Qual. Health Res.* **2015**, *25*, 1212–1222.
28. Maxwell, J.; Chmiel, M. Chapter 37: Generalization in and from Qualitative Analysis. In *The SAGE Handbook of Qualitative Data Analysis*; Flick, U., Ed.; SAGE: Thousand Oaks, CA, USA, 2014.
29. Quinlan, A.; Berbes-Blazquez, M.; Haider, L.J.; Peterson, G.D. Measuring and assessing resilience: Broadening understanding through multidisciplinary perspectives. *J. Appl. Ecol.* **2016**, *53*, 677–687.
30. De Moel, P.; Verberk, J.Q.J.C.; van Dijk, J.C. *Drinkwater-Principes en Praktijk;* Sdu uitgevers: Den Haag, The Netherlands, 2004.

31. Vitens. *Zicht op Water; Langetermijnvisie Win-Infrastructuur 2010–2040;* Vitens: Zwolle, The Netherlands, 2011.
32. Rijks Instituut voor de Drinkwatervoorziening. *Rapport inzake een onderzoek naar de mogelijkheid tot het vergroten van de capaciteit van de waterwinplaats "Het Engelse Werk" bij Zwolle van de Waterleiding Maatschappij Overijssel N.V*; Rijks Instituut voor de Drinkwatervoorziening: Amsterdam, The Netherlands, 1959.
33. Ministerie van Verkeer en Waterstaat, Rijkswaterstaat (RWS); Hoofdkantoor van de Waterstaat (HKW). Anders omgaan met water; waterbeheer in de 21 ste eeuw. Available online: http://publicaties.minienm.nl/documenten/anders-omgaan-met-water-waterbeleid-in-de-21e-eeuw-kabinetsstand (accessed on 15 January 2020).
34. Grondwaterwet waterleidingbedrijven. Available online: https://www.bibliotheek.nl/catalogus/titel.830031995.html/grondwaterwet-waterleidingbedrijven--wet-van-21-juli-1954--stb/ (accessed on 17 January 2020).
35. Ministerie van Verkeer en Waterstaat. De Waterhuishouding van Nederland; tweede nota waterhuishouding. Available online: http://publicaties.minienm.nl/documenten/de-waterhuishouding-van-nederland-1984-tweede-nota-waterhuishoud (accessed on 17 January 2020).
36. Ministerie van Verkeer en Waterstaat. De waterhuishouding van Nederland (1968) (eerste nota waterhuishouding). Available online: http://publicaties.minienm.nl/documenten/de-waterhuishouding-van-nederland-eerste-nota-waterhuishouding (accessed on 17 January 2020).
37. Ministerie van Verkeer en Waterstaat. Derde nota Waterhuishouding: water voor nu en later. Available online: https://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/@176068/nota/ (accessed on 17 January 2020).
38. Ministerie van Verkeer en Waterstaat. *Vierde Nota Waterhuishouding;* Ministerie van Verkeer en Waterstaat: Den Haag, The Netherlands, 1997.
39. Ministerie van Verkeer en Waterstaat. *Structuurschema Drink—En Industriewatervoorziening;* Ministerie van Verkeer en Waterstaat: Den Haag, The Netherlands, 1976.
40. Ministerie van Verkeer en Waterstaat. Grondwaterwet. Available online: https://wetten.overheid.nl/BWBR0003406/2006-03-08 (accessed on 17 January 2020).
41. Ministerie van Verkeer en Waterstaat. *Nationaal Waterplan 2009–2015;* Ministerie van Verkeer en Waterstaat: Den Haag, The Netherlands, 2009.
42. Waterleiding Maatschappij Overijssel. *Inventarisatie Engelse Werk*; Zwolle: Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1990.
43. Rijks Geologische Dienst. *Geologisch onderzoek pompstation Zwolle "Engelse Werk" bij Zwolle; Uitgebracht bij brief no. 781141 van 28 juli 1978 aan Stichting Waterwinningsbedrijf Zwolle en omgeving;* Rijks Geologische Dienst: Haarlem, The Netherlands, 1978.
44. Waterleiding Maatschappij Overijssel. *Herkomst van het opgepompte water uit het ondiepe watervoerende pakket met behulp—van het chloride—verband IJsselwater-ruwwater/pompput*; Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1985.
45. Waterleidingmaatschappij Overijssel. *Bentazon in de pompputten te Engelse Werk: ontwikkeling vanaf 1987 tot heden;* Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1994.
46. Waterleidingmaatschappij Overijssel, afdeling Onderzoek. *Aanvullende informatie betreffende de kleiige afzettingen van de formatie van Tegelen;* Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1988.
47. Rijks Geologische Dienst. *Lithostratigrafische beschrijving boring 21G-502 nabij pompstation "Engelse Werk" te Zwolle*; Rijks Geologische Dienst: Haarlem, The Netherlands, 1992.
48. Grontmij. *Drinkwaterwinstation 'Het Engelse Werk'. Rapportage van berekeningsresultaten met betrekking tot varianten putverplaatsing*; Grontmij: Arnhem, The Netherlands, 2001.
49. Ministerie van Verkeer en Waterstaat. (1994–1995). *Meerjarenprogramma Infrastructuur en Transport 1995–1999 Kamerstuk Tweede Kamer 1994–1995 kamerstuknummer 23903 ondernummer 2*; Ministerie van Verkeer en Waterstaat: Den Haag, The Netherlands, 1994.
50. Waterleiding Maatschappij Overijssel. *Integraal Plan Drinkwatervoorziening Overijssel*; Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1995.
51. Waterleiding Maatschappij Overijssel. *Drinkwaterplan 1997–2000*; Waterleiding Maatschappij Overijssel: Zwolle, The Netherlands, 1997.
52. Waterleidingmaatschappij Overijssel. *Integrale Drinkwatervoorziening Overijssel II*; Waterleidingmaatschappij Overijssel: Zwolle, The Netherlands, 1999.

53. Waterleiding Maatschappij Overijssel en Waterbedrijf Gelderland. *Lange termijnplan Drinkwater WMO-WG*; Waterleiding Maatschappij Overijssel en Waterbedrijf Gelderland: Zwolle, The Netherlands, 2002.
54. Arcadis. *Hanzelijn, Engelse Werk, Risico analyse t.p.v. spoorbaan*; Arcadis: Zuidas, The Netherlands, 2004.
55. TAUW. *Grondwaterkwaliteit Engelse Werk, gebied Schelle-Oldeneel (buurtschap IJsselzone Zwolle);* TAUW: Deventer, The Netherlands, 2004.
56. Vitens. *Heroriëntatie verplaatsing winning produktie locatie Engelse Werk*; Vitens: Leeuwarden, The Netherlands, 2006.
57. DHV. *MER Engelse Werk; Naar een duurzame waterwinning*; DHV: Amersfoort, The Netherlands, 2006.