

Innovations in urban water management to reduce the vulnerability of cities

Feasibility, case studies and governance



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Innovations in urban water management to reduce the vulnerability of cities

Feasibility, case studies and governance

Proefschrift

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Summary

Current urban water systems are criticised by many scholars. Negative aspects of the current urban water system include: effects of urban runoff on aquatic ecosystems, the lack of recycling of nutrients, the use of purified water to transport waste, land subsidence, high investments and maintenance costs, and the lack of flexibility to cope with future challenges. Cities show parasitic behaviour. They extract all required resources from the surrounding area and after using them, discharge the pollutants to this area. Cities hardly use internal resources of water, energy and nutrients and require more and more space. Envisaged future urban water systems aim to reduce the vulnerability of cities and ecosystems. The research was focused on surface water, stormwater and groundwater within cities. In particular, opportunities that these components of the urban water system offer to reduce vulnerability of cities were studied. The overarching aim of this research was to develop understanding how innovations in urban water management can be realised. This required three things: 1) understanding of the current system, 2) knowledge of innovations and 3) knowledge how to implement and mainstream these innovations in a societal context. To address these three aspects, this research applied vulnerability theory to contribute to better understanding of the current situation. Additionally, the technical feasibility of concepts that use the urban water surface water and urban groundwater to reduce the vulnerability of cities to flooding, droughts and energy scarcity was studied. Next to studying the technical feasibility, the case studies were also used to develop insights in mechanisms that determine adoption and mainstreaming of technical innovations. The results of the case studies were further substantiated through comparison with scientific theories, findings from literature, and comparison with the general results of a national survey among urban water management professionals.

A literature survey was done to make an overview of theoretical concepts of vulnerability. Based on the results of this research, vulnerability was defined as a framework that consists of four components. Threshold capacity is the ability of a society to build up a threshold against variation in the environment in order to prevent damage. Coping capacity is the capacity to reduce damage in case of a disturbance that exceeds the damage threshold. The third component, recovery capacity refers to the capacity to recover to the same or an equivalent state as before the disaster. Finally, adaptive capacity is the capacity of a society to anticipate on uncertain future developments. This includes catastrophic, not frequently occurring disturbances like extreme floods and severe droughts. The vulnerability framework shows that vulnerability capacities are connected. Increasing one vulnerability capacity potentially decreases one or more of the other capacities. Including all four capacities of the vulnerability framework enables better understanding of water and climate related vulnerability of urban areas. Moreover, the framework can assist in developing more complete water management strategies to reduce vulnerability. Based on this framework it can be concluded that in the Netherlands, current strategies for water supply and flood control management mainly focus on the first capacity of vulnerability by increasing threshold capacity. The current water management system is optimised with the objective of reducing the risk.

One of the objectives of this research was to learn from other countries in reducing vulnerability of cities to flooding and droughts. The situation in Japan was in particular interesting with regard

to climate adaptation of urban water systems. This country has already an extreme climate that causes both floods and droughts. Moreover, similar to the Netherlands, it is a highly urbanized, industrial country with a high percentage of invested capital and population in flood prone areas, including areas under sea level. Thus, the systems that are in place in Japan can provide us with ideas how Dutch urban water systems could function in the future. Japan is a country that is frequently exposed to all kinds of natural hazards including flooding and droughts. In Japan, there are many examples of urban water management innovations that increase coping and recovery capacity. A wide diversity of technologies is available to adapt to changes in the physical conditions. However, also in Japan the flexibility of the centralised main urban water management infrastructure seems low. Based on the vulnerability analysis, it can be concluded that in Japan all four capacities of the framework are used to reduce vulnerability of urban lowland areas.

One of the main objectives of this research was to study the feasibility of using the local urban surface water and urban groundwater for new functions. Three technical concepts were investigated. The first technical concept is the use of local urban water resources. Results for De Draai, Heerhugowaard showed that an entirely self-supporting urban water supply is not feasible. However, even in a dry year such as 2003, less than 5% external supply is required on a yearly basis. New urban developments can therefore be much more self-supporting. Water quality analysis and proposed treatment schemes showed that it is technically possible to produce drinking water from local resources. The expected costs were low although substantially higher than connecting the district to the conventional system. Rainwater harvesting appeared to be a promising technology in this project. The expected drinking water demand reduction was up to 27% on a yearly base. Following this project, rainwater harvesting is still in the process to be included in the development plans of the municipality on a pilot scale.

The second technical concept is this research was the use of the urban water system as an energy source. Research results demonstrated that De Draai in Heerhugowaard can be self reliant for heating and cooling purposes by applying Aquifer Thermal Energy Storage supplemented with surface water heat collection (ATES+). The district does not need to rely on international gas distribution networks that might be disrupted in the future by geopolitical tensions, incidents or terrorism. Price fluctuations on the international energy market have only a small impact on the heat and cooling system of De Draai. Local energy supply can be regarded as an adaptive strategy to the uncertainties of the global energy market. The vulnerability of this district is lower than in case of a conventional system. By cooling the surface water with 1.5-1.6 °C in three summer months, enough heat is collected to compensate the entire residential heating and cooling demand. With the concept of ATES+, fossil fuels are no longer required to produce heat for indoor climate control. Heat from the urban surface water and urban groundwater is used for this purpose. Electricity is still needed to operate the system, however only for the transportation of heat instead of the production and transportation.

The third technical concept was the use of the urban surface water for urbanisation. Floating urbanisation has the potential to contribute to reduce vulnerability of delta areas. During floods it may contribute to coping capacity. Floating houses will adapt to the rising water level and they potentially function as emergency shelter during flooding. Because floating houses can be relocated, they are also flexible, which is a benefit to deal with uncertain future developments

such as climate change. Risks of floating urbanisation include the loss of open space, the technical quality of floating constructions, and unknown water quality impacts. A potential way to address this problem is capacity building through well-designed, well build, and well maintained demonstration projects that are carefully monitored and evaluated. This will produce experiential knowledge among contractors, local government employees, utilities and residents.

The second part of this research focused on the implementation and mainstreaming of innovations in urban water management. Theoretical frameworks that were used in this research include transition theory, the multilevel perspective and the receptivity continuum. Based on international literature and experience from the case studies, two conditions were identified that determine the implementation and mainstreaming. These conditions are: including urban water management innovations in spatial development, and stakeholder receptivity to urban water management innovations. The Rotterdam case study was done to study how innovations are included in official policy and spatial planning. Results of this study show that the development of urban water management policy is currently integrated with urban planning. Planners of urban water retention infrastructure successfully utilise the opportunities that urban revitalisation presents by considering the local context. The role of the envisioning project Rotterdam Water City 2035 has been crucial in changing towards a new perspective. In this policy innovation niche, for the first time urban planners and urban water experts developed a joint long term vision for the city. Because it was a non official policy, more radical ideas and a longer planning horizon were possible than in official policy documents. In this vision, water retention contributes to the upgrading of neighbourhoods by increasing living quality. Many innovations that were developed in the project were eventually included in official policy. Examples are green roofs, water retention squares and floating urbanisation. Mainstreaming was enabled by changes during the preceding years. It became increasingly clear the water retention objectives could never be realised in a conventional way. Consequently, urban water management professionals were receptive to the integrated approach that was applied in the project Rotterdam Water City 2035. Mainstreaming was further enabled by executive and political support and the presence of change agents in all participating organisations.

Next, an online survey study was done to gain insight in the potential for transformative change in the Dutch urban water management sector. The receptivity to transformative change is small. Even in the survey group of policy experts with a good overview of current urban water management issues, there is no perceived necessity to radically change urban water management practice. The professionals are convinced that the societal objectives in urban water management can be achieved by optimisation of the current centralised urban water system. In addition, cooperation with other sectors is necessary and five key factors are regarded top priority to be further improved: 1) Available knowledge about the local urban water system, 2) Trust between cooperating partners in urban water projects, 3) Experience in connecting water management and spatial planning, 4) Support and commitment of elected officials to sustainable water management, and 5) Involvement of citizens in urban water projects.

Another objective of the online survey study was to gain insight in the receptivity of professionals in the Dutch urban water management sector to innovative technologies. The study addressed five themes; experience with innovations in general, considerations to apply innovations, current knowledge level, perceived contribution to sustainability, and expected implementation

timeframe. The results showed that the respondents are well aware of the technical innovations and expect application in the near future. However, in general their experience with innovations is low. Most respondents that had a high knowledge level of a specific innovation had not been recently involved in projects in which this innovation was applied. Moreover, the respondents have a moderate appreciation of the potential contribution of these technologies to sustainable urban water management.

In this research, the following recommendations were made to decrease vulnerability of cities and make better use of the urban water management technologies to do so. The first recommendation was that cities start to build experience with using local water resources and local flood control solution in addition to centralised systems. They should move towards a portfolio of resources to decrease the dependency on large scale infrastructure and external resources. The second recommendation is to increase the adaptability of urban water infrastructure. The third recommendation is that urban water management policy makers include long term envisioning with multiple stakeholders as a standard component of urban water management policy to increase awareness of long term problems. The fourth recommendation is that policy makers adjust change policy according to the full receptivity continuum of the stakeholders that are expected to implement these changes. The advice is not to make better policy documents, but to work on better implementation of policy by taking into account the receptivity of the organisations that will have to implement it. The fifth recommendation is the creation of supportive institutional frameworks and legal incentives. This includes creating of legal space for organisations to execute tasks that indirectly contribute to the mission of the organisation yet do not directly fit within their responsibility. The last recommendation is to create a commercial market for urban water management innovations. These recommendations can contribute to better implementation and mainstreaming of urban water management innovations in order to reduce the vulnerability of cities.

Samenvatting

Innovaties in het waterbeheer om de kwetsbaarheid van steden te verminderen¹

Hoe kan het stedelijk watersysteem worden ingezet om de kwetsbaarheid van steden terug te brengen, onder andere door beter gebruik te maken van lokale bronnen? Vier jaar geleden stelden we dit vast als belangrijke vraag van het onderzoek ‘Transities naar een duurzamer stedelijk waterbeheer.’ Nederlandse steden kiezen regelmatig voor weinig veerkrachtige maatregelen in het watersysteem waarbij de focus ligt op de korte of middellange termijn. De meeste maatregelen vallen onder de optimalisatie van het bestaande systeem door efficiency verbetering. Deze strategie lijkt overzichtelijk en rationeel, maar juist door te kiezen voor deze strategie maken steden zich kwetsbaar, omdat toekomstige veranderingen in klimaat, landgebruik en technologie niet vast maar dynamisch en onzeker zijn. Daarnaast onttrekken steden steeds meer grondstoffen aan hun omgeving. Ze zijn volledig afhankelijk geworden van hun omgeving en maken zich daardoor nog kwetsbaarder voor verstoring en verandering in diezelfde omgeving. Daarom is gezocht naar lokale concepten van waterhuishouding en watervoorziening waardoor een stad meer robuust en veerkrachtig wordt. Naast de technische aspecten van die nieuwe concepten is onderzocht welke factoren bepalen of organisaties zoals een gemeente of een waterschap haalbare innovaties ook daadwerkelijk gaan toepassen. Daartoe is de ontvankelijkheid van waterbeheerders voor verandering in beeld gebracht.

Verminderen van kwetsbaarheid

De kwetsbaarheid van een stad wordt niet alleen bepaald door het vermogen van de beheerder om schade door bijvoorbeeld droogte en wateroverlast te voorkomen. Ook het vermogen om schade te beperken en te herstellen zijn van belang. Uiteindelijk wordt de kwetsbaarheid van steden voor droogte en wateroverlast bepaald door vier capaciteiten.

- Structurele capaciteit: het vermogen om schade te voorkomen
- Schadereductie capaciteit: het vermogen om schade te reduceren als het misgaat
- Herstel capaciteit: het vermogen om het systeem weer op orde te krijgen
- Adaptieve capaciteit: het vermogen om in te spelen op onzekere ontwikkelingen zoals klimaatverandering

De kwetsbaarheid van een stad voor toekomstige droogte kan worden verlaagd door gebruik te maken van lokale bronnen van water in steden zoals regenwater, effluent, en oppervlaktewater naast de traditionele centrale watervoorziening, zodat steden tijdens droogte niet louter afhankelijk zijn van één bron. Het vermogen om droogteschade te reduceren neemt daarmee toe. Een andere manier om de kwetsbaarheid van een stad te verlagen is een klimaatrobuuste inrichting van de bebouwde omgeving. Dit reduceert de schade tijdens wateroverlast. Dit is van groot belang, gezien het gegeven dat droogte en wateroverlast vanwege klimaatverandering vaker voor zullen komen. Drie innovatieve concepten zijn in het kader van deze studie uitgewerkt.

¹ This summary is based on the following publication: De Graaf, R.E., R. Dahm, F.H.M. van de Ven, en W. Dassen (2009) Innovatief waterbeheer vermindert stedelijke kwetsbaarheid. Accepted for publication in *H2O*

Stedelijk water als energiebron

Een voorbeeld van een nieuw concept waarbij gebruik wordt gemaakt van lokale bronnen, is het gebruik van het stedelijk watersysteem als energieleverancier. In de wijk De Draai te Heerhugowaard is het concept uitgewerkt en getoetst voor circa 2800 woningen. In de zomermaanden onttrekken pompen warmte aan het oppervlaktewater en slaan dit, met behulp van warmte koude opslag (WKO), op in de bodem. In de winter kan deze warmte gebruikt worden voor verwarming van woningen en andere gebouwen. De resultaten geven aan dat de CO₂ uitstoot met 60% afneemt ten opzichte van een conventioneel systeem met van CV ketels. Met een terugverdientijd van 10 jaar is het concept economisch rendabel. Men is niet langer afhankelijk van energietransport, omdat omgevingswarmte in plaats van aardgas wordt gebruikt voor de verwarming van woningen. Hiermee zet een gemeente een stap richting een CO₂ neutrale en minder afhankelijke energievoorziening. Door de diversificatie van energiebronnen versterkt de structurele capaciteit en vermindert de kwetsbaarheid. Daarnaast treedt in de zomer een beperkte afkoeling van het oppervlaktewater systeem op waardoor de verwachte temperatuurstijging van het water en van de stad ten gevolge van klimaatverandering wordt verminderd. Het afkoelen van het oppervlaktewatersysteem heeft bovendien een positief effect op de waterkwaliteit.

Stedelijk water als bron voor watervoorziening

Voor dezelfde wijk in Heerhugowaard is de haalbaarheid van een volledig zelfvoorzienend watersysteem onderzocht; inclusief water voor de drinkwatervoorziening. In een droog jaar zoals 2003, bedraagt de jaarlijkse aanvoer die van buiten de wijk komt minder dan 5% (53.000 m³ of 34 mm). Analyse van de waterkwaliteit en de voorgestelde zuiveringstechnologie laten zien dat het technisch haalbaar is om drinkwater te produceren uit lokaal oppervlaktewater. De te verwachten kosten zijn aanzienlijk hoger dan bij conventionele watervoorziening. Ook het gebruik van regenwater om de drinkwatervraag te reduceren is onderzocht. De reductie in watervraag kan oplopen tot 27% als alle woningen van regenwatertanks worden voorzien. De besparing in kosten is beperkt namelijk € 118,- per jaar per huishouden door een lager drinkwater gebruik. Indien ook de rioolheffing en zuiveringsheffing afhankelijk zou worden gemaakt van het waterverbruik dan valt de besparing hoger uit. Het gebruik van lokale waterbronnen maakt steden minder afhankelijk van een enkele externe waterbron. Deze diversificatie van bronnen levert ook een bijdrage aan het vermogen van steden om zich aan te passen aan mogelijke toekomstige droogtes.

Stedelijk water als woonplek

Het derde innovatieve concept is het gebruik van stedelijk oppervlaktewater als plaats voor verstedelijking. In stedelijke gebieden neemt oppervlaktewater steeds meer ruimte om te voldoen aan het Nationaal Bestuursakkoord Water. De doelstelling van extra waterberging is het voorkomen van wateroverlast en inspelen op de mogelijke effecten van klimaatverandering. Door de aanleg van grote percentages oppervlaktewater in nieuwbouwwijken komt de gebiedsexploitatie onder druk te staan. Meervoudig ruimtegebruik door drijvend bouwen of bouwen boven water biedt hier een oplossing. Tegelijkertijd is drijvende bebouwing een flexibele en adaptieve manier van bouwen die kansen biedt om wensen van bewoners in de gebiedsontwikkeling mee te nemen.

Lessen uit het buitenland

Om onze steden minder kwetsbaar te maken voor de effecten van klimaatverandering, is het nuttig te kijken naar landen die nu al te maken hebben met een extreem klimaat zoals Japan en Australië. In Japan heeft men vanwege de extreme geografische omstandigheden ingezien dat schade niet altijd te voorkomen is. Daarom heeft men geïnvesteerd in stedelijk waterbeheer innovaties die de schade reduceren en het herstelvermogen vergroten. Voorbeelden zijn overstromingsbestendige gebouwen, superdijken en een groot verschil tussen straatpeil en vloerpeil. Hierdoor is waterberging in het stedelijk gebied mogelijk ondanks ruimtegebrek. Aangepast waterbeheer vermindert op deze manier de kwetsbaarheid van het stedelijk gebied. In Australië hanteert men een portfolio-aanpak bij het gebruik van lokale stedelijke waterbronnen. Door een grote diversiteit aan waterbronnen, zoals effluent, regenwater, grijswater en grondwater vergroot men de flexibiliteit om in te spelen op klimaatverandering. Australië besteedt daarmee aandacht aan structurele capaciteit, schade reductie capaciteit, herstelcapaciteit en adaptieve capaciteit. Zo zien we dat in het buitenland innovatieve concepten voor het waterbeheer de kwetsbaarheid van de stad verminderen.

Van kennis naar praktijk

Wat bepaalt nu of deze innovaties in de praktijk van het stedelijk waterbeheer toegepast worden? Het blijkt dat de keuze om over te gaan tot het toepassen van een innovatie sterk wordt bepaald door twee voorwaarden waaraan moet worden voldaan. Allereerst dient de innovatie opgepakt te worden in het proces van ruimtelijke ontwikkeling. Daarnaast is van belang dat waterbeheerders openstaan voor de innovatie, kansen zien voor hun eigen organisatie, en de benodigde kennis en vaardigheden hebben. Voor de eerste voorwaarde is het van groot belang dat waterbeheerders samenwerken met ruimtelijke ordenaars en stedenbouwkundigen. Een studie naar 'Rotterdam Waterstad 2035' laat zien dat samenwerking tussen deze disciplines kan leiden tot een omslag in het denken waar beide partijen overtuigd zijn van het nut van samenwerking. Waterberging wordt beter gerealiseerd door inpassing in het proces van stedelijke vernieuwing. Daarnaast biedt water kansen om een stad aantrekkelijker te maken voor bewoners en bedrijven. Een goede manier om de samenwerking op gang te brengen is het starten van een lange termijn visievormingsproces. In Rotterdam was het hierdoor mogelijk innovatieve ideeën te genereren voor een lange tijdshorizon. Toen meerdere organisaties hun enthousiasme uitten over deze visie, werden ideeën zoals groene daken, waterpleinen en drijvende gebouwen uit deze visie opgenomen in het officiële waterplan. Door de koppeling met stedelijke vernieuwing en klimaatadaptatie kwam het thema 'water' hoger op de politieke agenda.

De tweede voorwaarde die bepaalt of technisch haalbare innovaties in de praktijk worden toegepast is de mate waarin waterbeheerders openstaan voor deze innovaties. Om deze bereidheid te meten werd een landelijke enquête gehouden onder stedelijk waterbeheerders van zowel waterschappen als gemeenten. De resultaten van deze enquête laten zien dat de respondenten goed op de hoogte zijn van de drie eerder beschreven innovaties. Bovendien verwachten zij dat deze innovaties in de nabije toekomst worden toegepast in het beheersgebied waar zij werkzaam zijn. Het blijkt echter dat weinig respondenten persoonlijk ervaring hebben opgedaan met een van deze innovaties. Bovendien schatten zij de positieve bijdrage van bovenstaande innovaties aan duurzaam stedelijk waterbeheer als matig tot redelijk.

Wat betekent dit? Dat ervaringskennis met een innovatie voor een waterbeheerder niet als strikt noodzakelijk wordt gezien om toch innovatieve concepten toe te passen. Men verwacht dat innovaties worden toegepast maar tegelijkertijd verwacht men ook dat dit maar een beperkte

bijdrage zal leveren aan het bereiken aan duurzaam waterbeheer. Nieuwe concepten worden kleinschalig in demonstratieprojecten toegepast maar blijven vrij geïsoleerd in hun invloed op het overkoepelende systeem. Voor een betere doorwerking van kennis naar praktijk is het daarom van belang om meer aandacht te besteden aan de kennisdoelen en leerdoelen van demonstratieprojecten in plaats van de technische demonstratie zelf. Innovaties zullen uiteindelijk moeten worden herhaald en opgeschaald willen zij doorbreken in de algemene praktijk van het stedelijk waterbeheer. Het is daarom van belang dat stedelijk waterbeheerders aandacht geven aan draagvlak en innovatieve projecten blijven herhalen en tegelijk verbeteren.

Aanbevelingen

Om de kwetsbaarheid van onze steden te verminderen zijn op basis van het uitgevoerde onderzoek een aantal aanbevelingen geformuleerd:

- Bouw ervaring op met lokale concepten van watervoorziening en waterrobuuste verstedelijking door middel van demonstratieprojecten. Hierdoor neemt het aantal beschikbare opties om in te spelen op de toekomst toe, en daarmee het adaptieve vermogen.
- Verhoog de adaptiviteit van stedelijk watersystemen door te bouwen voor een kortere levensduur of kies bewust voor redundantie. Hierdoor wordt het eenvoudiger in te spelen op onzekere toekomstige ontwikkelingen. Alleen als men de toekomst kent, bouwt men voor de eeuwigheid.
- Neem lange termijn visievorming op als standaard onderdeel in het stedelijk waterbeleid. Hierdoor neemt het bewustzijn voor lange termijn problemen als droogte, bodemdaling, klimaatverandering en demografische ontwikkelingen toe. Het biedt de mogelijkheid om interdisciplinair samen te werken en buiten gebaande paden te denken.
- Neem de bereidheid van waterbeheerders om innovaties toe te passen integraal mee bij het ontwikkelen van waterbeleid. De waterbeheerders moeten overtuigd zijn dat een andere manier van werken voordelen biedt voor hun organisatie. Creëer statutaire en juridische ruimte voor organisaties om te participeren in multifunctionele watersystemen en innovaties. Het toepassen van innovaties betekent vaak dat belanghebbenden nieuwe rollen gaan vervullen. Zo kan een waterschap betrokken raken bij de aanleg en onderhoud van groene daken, bij de commerciële uitgifte van waterkavels of bij concessies voor warmtewinning.
- Stimuleer de ontwikkeling van een commerciële markt voor stedelijk waterbeheer innovaties. Innovaties in het stedelijk waterbeheer zullen pas doorbreken als zij worden opgepakt door bouwers en projectontwikkelaars. Daarom is het van belang dat marktwerking ontstaat voor deze innovaties. Het faciliteren van maatschappelijke en economische stimulansen, zoals strengere normen, het uitreiken van prijzen en bewustwording bij burgers kan dit proces versnellen.

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1 Introduction

1.1 Background

1.1.1 Urban water systems

Urban water systems consist of five interrelated types of water in urban areas: groundwater, surface water, stormwater, drinking water and wastewater (Van de Ven, 2006a). Urban water management is defined as the management of quantity and quality of stormwater, groundwater and surface water in urban areas. This area is the lower part in figure 1.1 that is called the ‘watersystem’. It is the study area of urban water management engineers. It is also the focus area of this thesis that describes urban water management innovations to reduce vulnerability of cities. Innovations are defined as technologies that enable using the urban water system for new functions. The upper part is the ‘water chain’ which includes drinking water supply, sewer systems and wastewater treatment. This is the study area of sanitary engineers. Urban water systems have two sources of water: precipitation and external drinking water supply through pipes.

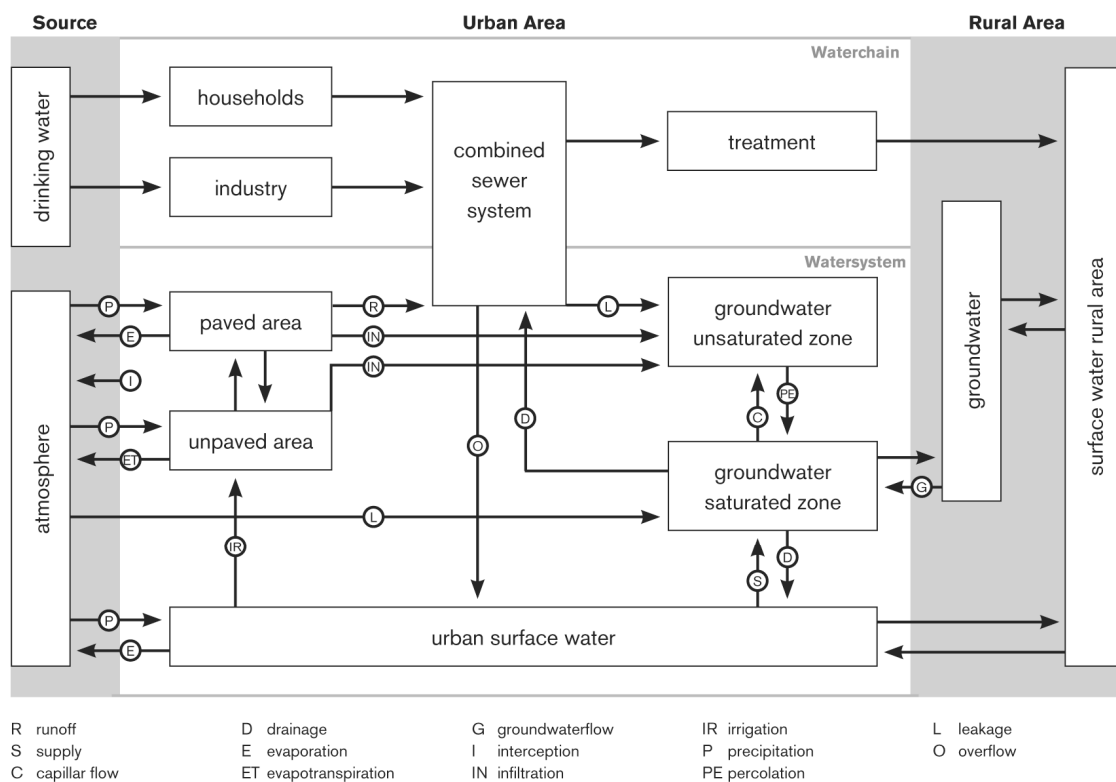


Figure 1.1 Schematisation of the urban water system (combined sewer system)

Rainwater is converted to stormwater when it falls on paved and unpaved surfaces. In the Netherlands, predominantly combined sewer systems have been implemented in the past, this is the system that is shown in figure 1.1. In these systems, stormwater is transported with wastewater in the same pipe. During heavy rainstorms the capacity of the sewer system is not sufficient to transport all runoff. In that case, combined sewer overflows (CSO's) take place. This leads to the emission of diluted wastewater and sewage sludge to the urban surface water. In

Dutch national policy, it is now generally accepted that relatively clean stormwater should not be mixed with wastewater flows (e.g. VROM, 2003; VROM 2006).

Separate sewer systems were implemented in the Netherlands from the 1970's. Disconnection of paved surfaces from the combined system, and infiltration of stormwater has been widely adopted by municipalities in the Netherlands since the end of the 1980's.

1.1.2 History of urban water systems

Based on the work of Van der Ham (2002), Hooimeijer (2008) describes the following phases in the development and design of polder cities in the Netherlands. In particular, the relation of cities with the regional water system is described. In order to make the marshlands suitable for urbanisation, it was crucial to manage surface water and groundwater levels artificially. The phases below can be considered as the development of the Dutch approach to urban water management in polder cities.

1. Acceptation (until 1000)
2. Defensive (1000-1500)
3. Offensive (1500-1800)
4. Early manipulative (1800-1890),
5. Manipulative (1890-1990)
6. Adaptive manipulative (1990-today).

The six phases describe a growing influence of technology over the natural water system. There is a gradual change from adapting settlements to the water system (first phase) to the construction of the first dikes and sluices (second phase) and the reclamation of polders (third and fourth phases). The fifth phase is characterised by the separation of the professions of civil engineering and urban design. In this phase, polder areas were integrally raised with sand to make them suitable for urbanisation, water levels were controlled by pumping stations. Consequently, urban designers were provided a clean sheet for urban expansion plans. All water problems could be solved by civil engineers (Hooimeijer, 2008). As a result, water aspects were no longer incorporated in the urban design. The last phase is characterised by an approach in which cities have to adapt more to the natural system instead of manipulating it. This is caused by the rise of environmental awareness in the 1970's and climate change problems in 1990's. As a result, more water storage is constructed in urban areas and the link between water management and urban planning has become more important again. In the Netherlands, there has been a change in perception on water management. Van der Brugge et al. (2005) described how over the past decades, water management approach has changed from a technical approach to a more integrative approach.

Brown et al. (2008) described six distinct, cumulative transition states in the development of urban water management in Australia. These phases also include the development of water supply. The same pattern can be found in other Western countries. These phases roughly correspond to the phases 4 to 6 the Hooimeijer framework.

Water supply city

Industrialisation and rapid urbanisation caused severe public health problems and water shortage by the middle of 19th century. In the Netherlands, this created room for the first piped water supply in the 1850's (Geels, 2005). However, Geels also describes that for diffusion of this technology several political and cultural developments were instrumental. The required

investment threshold was exceeded by further urbanisation and economic growth. This resulted in sufficient mass of people that were willing and able to pay for piped drinking water from public taps or a private connection.

In addition, development of hygiene and health sciences provided important insights in the relation between polluted drinking water and epidemics. The work of Snow (1849) who discovered a connection between the cholera epidemic and the use of polluted drinking water in the city of London, contributed to the increased importance of hygienic issues in society. In the Netherlands, cleanliness became an important norm for the middle classes in the 1860's and 1870's. The rise of workers unions and further expansion of voting rights provided strong incentives for politicians to deal with the public health problems.

Sewered city

The first sewers consisted of gutters that were constructed for stormwater drainage. Societal concerns about public health, criticism from hygienic doctors and engineers, rapid urbanisation, changes in legislation and normative and behavioural changes contributed to the diffusion of sewer systems by the beginning of the 20th century (Geels, 2006). The Netherlands was relatively late with the implementation of sewer systems. The Hague constructed the first sewer system in 1893, Amsterdam in 1913.

Drainage city

The post-war reconstruction period was characterised by rapid economic growth and urbanisation. The car became a common method for transportation. As a result, there was a huge increase of paved surfaces that generated stormwater. Stormwater was transported away from urban areas as quickly as possible by combined sewer systems. New urban expansions were integrally raised with sand. The amount of surface water in these developments was limited.

Waterway city

Environmental concern in the 1970's led to a growing influence of ecologists in water management (Van der Brugge et al., 2005). Environmental protection became an important issue. Wastewater treatment plants were constructed to improve water quality and to protect ecology in receiving waterways. Separated sewer systems were constructed to improve water quality. In the 1980's, diffuse pollution and source control of pollutants instead of an end-of-pipe approach, emerged as an important theme in urban water management (e.g. TNO-CHO, 1985; NWRW, 1989). Because source control deals with distributed pollution, the connection with spatial planning became more important.

Watercycle city

Since the 1990's, there has been a rising importance of the concept of sustainability. Concerns about the limits of water resources became drivers for water conservation and water recycling. In Utrecht, the Netherlands, a third pipe network feasibility study was done for the Leidsche Rijn urban expansion in 1994 (Rijke, 2007) and for IJburg in Amsterdam in 1997 (Van der Hoek et al., 1997). The main purpose was not to use purified drinking water for the transportation of waste. A misconnection between the third pipe system and the drinking water system stopped this development in the Netherlands. According to Brown et al. (2008) the watercycle city has not yet been implemented as mainstream practice in any city. It is still limited to academic discussions and small scale demonstration projects.

Water Sensitive City

The Water Sensitive City is a potential future state of urban water systems. The main drivers are intergenerational equity and climate change. It will be further discussed in this chapter in the section about future water systems.

1.1.3 Criticism on current urban water systems

Current urban water systems are criticised by many scholars for their inherent unsustainability. The construction of centralised water infrastructure in the 19th and 20th century has successfully tackled most public health problems, part of urban flooding problems, and localised environmental problems (Butler and Parkinson, 1997). Predominantly centralised large scale 'hard' infrastructures were constructed for instance dams, concrete embankments, sewers, and water supply networks. These systems brought huge benefits for society. However they also had serious ecological, social and economic costs (Gleick, 2003). Negative aspects of the current urban water system include: effects of urban runoff on aquatic ecosystems, the lack of recycling of nutrients, the use of purified water to transport waste, land subsidence, high investments and maintenance costs, and the lack of flexibility to cope with future challenges. Cities show parasitic behaviour (De Graaf and Van de Ven, 2006). They extract all required resources from the surrounding area and after using them, discharge the pollutants to this area. Cities hardly use internal resources of water, energy and nutrients and require more and more space.

Stormwater impacts on ecosystems

Centralised systems for transportation and collection of stormwater were implemented to drain stormwater runoff out of the urban area as quickly as possible. It has been generally acknowledged that the conventional way of dealing with stormwater in combination with rapid urbanisation, leads to significant adverse hydrological and ecological changes (Rivard et al., 2005).

Even at low levels of urban development, the discharge of urban runoff by centralised collection and transportation systems has detrimental effects on aquatic ecosystems (Booth and Jackson, 1997). Reported effects on receiving waters include: flooding, erosion, sedimentation, temperature rise, dissolved oxygen depletion, eutrophication, toxicity, and reduced biodiversity (Marsalek, 1998). A negative exponential relationship between the expansion of paved surface area and receiving water quality has been observed (Ellis, 2008).

In the Netherlands the situation is different because the water quality in the rural surroundings is often worse than the stormwater quality from separated sewer systems in urban areas. This is due to the intensive agriculture and the excessive use of fertilisers.

Newman and Mouritz (1996) link the problem of urban runoff to the increase of car mobility and the construction of cities that depend on car based mobility for their functioning. This has led to large areas of sealed surfaces. They state that stormwater from bitumen based cities is excessive in quantity and quality.

Nutrient management

The linear nature of centralised urban water infrastructure leads to flows of nutrients, chemicals and substances that can accumulate in aquatic ecosystems (Butler and Parkinson, 1997). The absence of closed cycles will lead to a lack of nutrients in some places and accumulation in others (Berndtsson and Hyvönen, 2002). Therefore, provision of sanitation should be combined with the developments of methods and technologies that enable recycling of nutrients from wastewater to agriculture (Niemczynowicz, 1999).

Rock phosphate is a finite resource and should therefore be recycled instead of being disposed to landfills, or discharged to the aquatic environment where it accumulates in sediments. Proven phosphate reserves are sufficient for 100 years of economic use (Driver et al., 1999; Isherwood, 2000). According to some authors, decentralised local systems should be implemented for this purpose (Otterpohl et al., 1997; Zeeman and Lettinga, 1999). However, technologies are currently available and are being developed for phosphate recycling from wastewater that could also be applied in centralised systems (de-Bashan and Bashan; 2004).

Nitrogen is available in large quantities in the atmosphere. It is used to produce artificial fertilisers through ammonia synthesis (Haber Bosch process). Biological nitrogen removal and ammonia synthesis can be regarded as nitrogen recovery via the atmosphere (Wilsenach, 2006: 33). Industrial ammonia synthesis is vital for global food production to sustain the current size of human population. However, it has led to radical changes in the environment, including water and air pollution and a loss of biodiversity due to a huge increase in ammonia production (Erisman et al., 2008).

Water efficiency

Cities extract their water supply almost entirely from surrounding areas. Local water resources are hardly used. Water flow to cities is therefore an example of a linear flow. Although the urban water cycle is part of the hydrological cycle at a higher scale, water depletion of groundwater resources and the absence of using local water resources cause linear flow patterns at the city scale. Current urban water systems use purified water to transport waste. According to Butler and Parkinson (1997) conventional drainage systems use water extremely inefficiently. They regard this as the waste of a precious resource and unnecessary dilution of waste that requires end-of-pipe technology to extract solid waste components from the diluted wastewater stream.

Use of local water resources or water recycling could contribute to more cyclic water flows through the urban environment, and decrease impacts of cities on the surrounding areas. In the Netherlands 93,000 ha of nature area suffers from groundwater depletion (Vewin, 2004). In many cities groundwater resources are threatened due to overexploitation (Niemczynowicz, 1999).

Land subsidence

Urban groundwater management and soft soils lead to land subsidence in many urbanised delta areas. Examples of serious problems due to land subsidence are increased inundation frequency, increased flood impacts, salt water intrusion and groundwater nuisance. Groundwater overexploitation and groundwater drainage cause increase pore pressure and reduce pore space in compactable soils. This results in land subsidence.

Holzer and Johnson (1985) described 8 cities that suffered significant economic damage due to land subsidence. The cities were: Bangkok, Houston, Mexico City, Osaka, San Jose, Shanghai, Tokyo, and Venice. Continuing urbanisation of delta areas has increased the potential damage. Wei (2006) found that in Shanghai the direct economical loss caused by land subsidence was € 1.45 billion and the indirect economical lost is € 28 billion Euros in the period 1949-2000.

In the lowland areas in the Netherlands, soil compaction and oxidation of peat soils have resulted in land subsidence up to 5 cm per year (Van der Meulen et al., 2007). To reduce groundwater nuisance and maintain an unsaturated zone in the upper layer, groundwater levels are periodically decreased. This results in continuing land subsidence that has accumulated to several meters in certain areas. In addition, due to the protection of urban areas with dikes, natural sedimentation processes no longer take place. This has resulted in a cumulative sediment

deficit which makes it impossible for urbanised deltas to keep up with sea level rise (Van der Meulen et al., 2007).

Economic considerations

Large scale centralised urban wastewater systems are considered expensive. They are energy intensive and require high investments. However they are also cost effective if the costs are calculated per capita (Wilsenach, 2006). According to Ashley et al. (2007a), the continuing use of high-energy systems will become increasingly untenable. Massive investments cause problems for retrofitting and upgrading of densely built and populated urban areas (Kotz and Hiessl, 2005). Rising costs are caused by aging assets and higher quality standards (Barraqué, 2003).

Large water systems develop economies of scale but often lose the ability to provide small scale services and miss opportunities for local efficiencies. (Newman and Mouritz, 1996). In the Netherlands, the replacement value of the sewer system is € 62 billion (Rioned, 2009). Annual expenditure for operation and maintenance of the sewer system (wastewater treatment not included) is € 1,081 million or € 66 per capita. Although this may be relatively low compared to other public infrastructure, the annual costs for urban drainage in the Netherlands has risen 5% every year on average between 1990 and 2003 and is expected to rise further due to ageing of infrastructure and increasing societal demands (Hoeben and Gerritsen, 2005).

Lack of sustainability

According to many researchers urban water infrastructures should be structurally transformed because they are unsustainable in particular with regard to nutrient recycling and water efficiency (e.g. Otterpohl et al., 1997). The widely used definition of sustainable development from the Brundtland Report (WCED, 1987) is that 'sustainable development is meeting the needs of current generations without compromising the ability of future generations to meet their needs'.

Definitions that are used in urban water management describe sustainability as a balance between social, economic and ecological values. A sustainable approach should include sufficient flexibility in the system to accommodate future changes (Berndtsson and Jinno, 2008).

The concept of sustainability, however, still lacks consensus about the exact meaning. As addressed by Rijsberman and Van de Ven (2000) the interpretation of what is sustainable depends on personal values and perceptions of participants in a debate. Some define sustainability as economic efficiency whereas others are more focused on retaining the integrity of ecosystems. Butler and Parkinson (1997) state that sustainability is likely to remain ambiguous and without absolute definition.

Lack of flexibility

There are many drivers for the urban water system to change. Ashley et al. (2007a) mention three most important drivers for sewer systems: (1) environmental legislation, public attitudes and expectations, (2) land use and urbanisation and (3) energy and resource stress. Other drivers that are documented in literature are: privatised ownership of water infrastructure, new pollutants risks, new technologies, demographic developments, and the lack of sustainability of current systems (Lienert et al., 2006).

Climate change is more and more mentioned as a major driver for changing urban water systems (Ashley et al., 2007b). However, changing current urban water systems is difficult because they have life spans of decades and are characterised by considerable sunk cost (Hiessl et al. 2001). Pahl-Wostl (2005) suggests that the longevity of current water infrastructure and

management practices is insufficient to deal with fast changes and uncertainty. In case of uncertainty and recognised ignorance in predicting the consequences of technological development on complex natural systems, solutions have to be flexible. Irreversibility of consequences should be prevented (Harremoës, 2003).

The high technical lifetime of 50-100 years make urban water systems inflexible to adapt to future changes such as climate change (Kotz and Hiessl, 2005). Time horizons in urban water management are generally short, often five-year planning cycles (Ashley et al., 2007a). There is a clear mismatch between the planning horizon and the technical lifetime. The planning horizon does not go beyond the expected lifetime of the infrastructure, therefore only optimizing measures can be proposed in planning documents, unless the current infrastructure is demolished and replaced by a new system. This is a limitation on the adaptive potential of urban water infrastructure to uncertain effects of climate change and societal changes.

Institutional fragmentation and specialisation

Institutional fragmentation has resulted in functional silos in which part of the system is optimised in isolation of other system components (Wong, 2006a). This has led to a suboptimal overall system performance. Technical optimisation of a component of a large technical system may prevent system innovation. Moreover, it may lead to a technical and institutional lock in. Different organisations are responsible for the interrelated components of urban water systems. Fragmented accountability frameworks of urban water organisations leave limited room for action that diverges from statutory responsibilities. Institutional objectives of urban water management organisations are focused on performing prescribed task within legal frameworks. There is no defined responsibility for the overall urban water system. Reward mechanisms are based on fulfilling procedures, within the boundaries of projected costs and projected timeframes. Therefore, there are significant obstacles to fulfil roles that are different from the traditional role. However, the fulfilling of other roles is central to innovations in urban water management. This will be further elaborated in part 2 of this thesis.

The role of the specialist has co-evolved with institutional fragmentation of the water system. Harremoës (2002) argued that experts have to become highly specialised in order to receive recognition. This leads to a narrow interpretation of urban water issues and the use of expert terminology that makes cooperation between disciplines difficult. Saul (1992) described that experts in general are increasingly in a contradictory position. On one hand the expert has a rising autonomy in tiny slice of expertise. On the other hand, the expert is getting increasingly locked in a separated area of expertise, and is becoming increasingly powerless in society as a whole.

Fragmented urban development process

Next to institutional fragmentation, also the urban planning process itself is fragmented. As observed by Geldof (2005), western organisations often apply the serial planning approach. This approach is characterised by fragmentation of the urban development process in distinct steps of policy, planning, design, construction and maintenance. For each step, different stakeholders are responsible that are not involved in previous phases or follow up phases. The result is that communication between the phases takes place in the form of reports, documents and guidelines. Only transfer of explicit knowledge is possible and other forms of knowledge (e.g. tacit knowledge) will not be transferred to the next phase of the process. Original intentions of the policy are lost in the design phase when feasible measures are desired.

Lack of citizen involvement

Although urban water institutions increasingly use the term client, there is usually no freedom of choice for citizens to buy services other than those provided by centralised water infrastructure. Citizen involvement in urban water management that goes further than paying taxes and fees is rare. Professionals in specialised institutions are reassuring in the fact that they provide high level knowledge and will take care of the citizens' problems. According to Pahl-Wostl (2005), the lack of information and insufficient ability prevent citizens from meaningful participation in decision making processes with regard to current and future functioning of urban water systems. Involving the private sector is also problematic. Market mechanisms to successfully support innovation in urban water management are lacking and there are huge barriers for private sector participation in the urban water sector (Rothenberger et al., 2005).

1.1.4 Future urban water systems

The critique on current urban water systems has resulted in a large number of publications that outline properties and characteristics of future water systems. These systems are also expected to make use of opportunities such as utilisation of local resources. The characteristics of future water systems can be subdivided into categories of socio-economy, ecology, resource use and management.

Socio-economy

According to many authors (Larsen and Gujer, 1996; Butler and Parkinson, 1997; Berndtsson and Hyvönen, 2002) public health protection should remain a key function of urban water systems. This may include the supply of water and the removing of faecal matter from urban areas where it would cause disruption if it would accumulate.

Flood prevention is an important function of urban water systems. Because urban areas create paved surfaces, urban runoff is generated that should be managed to prevent pluvial flooding. According to Newman and Mouritz (1996), future cities should have increased soft surfaces for stormwater retention. Also Ellis (2008) argues that '3rd generation urban drainage' consists of the introduction of vegetative systems into the urban form to reduce surface water runoff.

Newman and Mouritz (1996) found economic, ecological and social benefits of community scale water management systems. Local systems often require lower initial investments than conventional systems and contribute to the local economy by facilitating use of receiving waters, increasing real estate value, and the development of eco-industry for the production of environmental technologies (Marsalek and Chocat, 2002). The Deltares' Water City (Van de Ven, 2009) provides a number of functional characteristics including: surface water as space, water as energy source, water as soil carrier and water to improve the urban landscape.

Ecology

Urban stormwater management should aim to protect downstream aquatic systems, remove pollutants and protect stormwater elements as a part of the urban landscape (Wong, 2006b). Stormwater control and management near the source is promoted as a paradigm to address the problems that were caused by conventional systems. This has led to the introduction of concepts such as: Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), Best Management Practices (BMP's) and Integrated Urban Water Management (IUWM). All of these concepts are characterised by a focus on source

control rather than end-of-pipe treatment of stormwater. Methods to locally attenuate stormwater include: filter strips, constructed wetlands, permeable pavements, bioretention systems, green roofs and infiltration systems. Marsalek and Chocat (2002) provide a comprehensive review of current technologies.

Resource use

Instead of a waste, stormwater should be considered as a valuable resource for water use functions that do not require the highest quality (Niemczynowicz, 1999). It is estimated that China and India will need all runoff that is generated to meet urban and agricultural water demand in the next 20 years (Jury and Vaux, 2005). Urban demand from water supply catchments should therefore be reduced (Wong, 2006b). Infrastructure that combines both centralised and decentralised water sources makes cities more flexible to adapt to external changes such as climate change. Gleick (2003) argued that community-scale, decentralised facilities must complement conventional centralised infrastructure.

Nutrient cycles of urban water systems should be closed through recycling and drinking water use for transportation of excreta should be abandoned (Berndtsson and Hyvönen, 2002). Some authors have therefore proposed urban agriculture as a function of urban water management (Larsen and Gujer, 1997; Niemczynowicz, 1999). This would allow for nutrient recycling on a local rather than on a global scale and would decrease the dependency of urban areas on the global system of food production.

Management

To address the problem of institutional fragmentation, an integrated and multi-disciplinary framework is required (Butler and Parkinson, 1997). According to Niemczynowicz (1999) the future challenges within urban water management will be to organise cross-sectoral stakeholder cooperation in order to introduce innovative water technologies, management systems and institutional arrangements. These systems should be able to meet the multiple objectives of equity, environmental integrity and economic efficiency, and at the same time achieve a high level of water services.

Rijsberman and Van de Ven (2000) demonstrated that urban water systems have to fulfil an increasing number of functions and are influenced by various conflicting values. Urban water management has a multi-functional and multi-stakeholder character. Stakeholders usually do not agree about the problems, objectives, and solutions. In addition, the required means are sometimes unknown. Thus, the connection with urban planning and development, that is the process through which spatial functions are determined and values are negotiated, is increasingly important.

Mouritz (1996) argues that the design of future water infrastructure should be developed by integrated planning and management of land, water and other resources. Also Van Rooy et al. (1998) state that water is a part of our environment and that water policies interact with urban planning policies. In addition, each development should aim to improve the functions of natural water system to maximise local environmental and economic benefits (Ellis, 1995).

The drivers that influence urban water systems are characterised by large margins of uncertainty. Moreover the expected lifespan of urban water infrastructure is high, often decades. Therefore, flexibility is considered a key required attribute of urban water systems (Butler and Parkinson, 1997). Boundary conditions are no longer considered stable. The adaptability of infrastructure therefore becomes a crucial attribute to adapt to changes in society and the

environment. According to Harremoës (2003) reliable predictions about the impact of technologies on the complex environment are lacking. Therefore there is no justification for irreversible decisions. According to the same author, decisions should be considered experiments that require monitoring to continuously improve our understanding of the system.

The active participation of the users is essential if local solutions are to be adopted (Butler and Parkinson, 1997). Pahl-Wostl (2006) listed a number of essential attributes for meaningful citizen participation including: access to comprehensive and timely information, capacity building and empowerment of citizens, reform of institutional settings to allow citizens to articulate their perspective, involvement in both envisioning of future management schemes and daily management. In addition, user fees could be made dependent on the effort made on private property to contribute to the overall system performance (Parikh et al., 2005). Citizens may play a more active role than the passive consumer in the provision of urban water services for instance as a producer of local water resources (Hegger, 2007). Based on the cited literature above, the envisaged characteristics of future water systems can be summarised as follows:

1. Socio economic
 - Public health protection
 - Flood control by local stormwater retention
 - Multi functional use of surface water
 - Water as carrier for the soil
2. Ecology
 - Protection of aquatic ecosystems
 - Water as carrier for the soil
3. Natural resource use
 - Closed nutrient cycles by recycling
 - Increased water use efficiency
 - Urban water systems as source of local water, energy and food resources
 - Flexible and adaptable urban water infrastructure
4. Management arrangements
 - Integration of water management and land use planning
 - Meaningful citizen involvement
 - Flexible and adaptable management arrangements
 - Cross sectoral stakeholder cooperation

1.2 Research questions

The previous section described properties of future urban water systems. The main objective of these properties can be understood as reducing the vulnerability of cities and ecosystems. Water related vulnerability has many aspects. For instance, the purpose of flood control is reducing vulnerability of cities to flooding. The impact of cities on aquatic ecosystems is reduced in order to decrease the vulnerability of these ecosystems to disruption resulting from human influence. Closing nutrient cycles and increased water use efficiency contribute to decreasing the vulnerability of urban areas by reducing their dependence on external resources.

One could argue that the main purpose of technology itself is to deal with variability in the environment to reduce the vulnerability of society. The first human technological advances such as tools, shelter and agriculture all contributed to a decreased vulnerability of human settlements

to sudden changes in the environment. In addition, the vulnerability concept is useful for reflection on a topic that includes social, ecological and technical components. The continuing functioning of these components in time can be described in terms of vulnerability. Therefore, the framework of vulnerability is used as the theoretical basis of this thesis. It will be further described in the next chapter.

The research was focused on surface water, stormwater and groundwater within cities. In particular, local scale opportunities that these components of the urban water system (fig. 1.1) offer to reduce vulnerability of water supply, energy supply and flood control in cities were studied. Current water supply, energy supply and flood control infrastructures of cities stretch out beyond the city scale. Therefore, chapter 2 applies the vulnerability framework on water supply and flood control in the Netherlands on a national scale. After this step, the research focused on local scale urban water management innovations that reduce the vulnerability of cities.

The overarching aim of this research was to develop understanding and insight how innovations in urban water management can be realised. This requires three things: 1) understanding of the current system, 2) knowledge of urban water management innovations and 3) knowledge how to implement these innovations in a societal context. However, implementation of innovations does not necessarily lead to significant change in urban water management. Innovations may remain confined to showcase demonstration projects. Therefore, an additional research objective was to identify mechanisms that determine the adoption of innovations in mainstream day-to-day professional practice. To address these aspects, this thesis describes vulnerability theory to contribute to a better understanding of the current situation. Additionally, the technical feasibility of concepts that use the urban water surface water and urban groundwater to reduce the vulnerability of cities was studied. Finally, this research addressed mechanisms that influence the adoption and mainstreaming of these technical concepts. These three components led to the following research questions.

A) Vulnerability

1. What is a useful framework to understand water related vulnerability of urban areas?
2. What can we learn from other countries in dealing with water related vulnerability?

B) Innovations in urban water management

1. How could innovations in urban water management be used to reduce vulnerability of urban areas?
2. What is the feasibility of these innovations in practical case studies?

C) Governance mechanisms

1. What mechanisms can be identified that influence mainstreaming of innovative concepts in urban water management?
2. What is the practitioner receptivity to changes in urban water management and application of innovative concepts?
3. What would be useful strategies and recommendations to achieve mainstreaming of innovations in urban water management to contribute to cities that are less vulnerable?

1.3 Research context

This thesis is based on results from the research project 'Transitions to more sustainable concepts of urban water management (Transitions SUW). This project (2005-2009) was executed by a consortium of 12 organisations as part of the research program Living with Water (Leven met Water). The consortium consisted of both researchers and practitioners. The project did not only include scientific objectives, but also practical objectives such as implementation of urban water management innovation. For more information about this project the reader is referred to the Appendix. One of the objectives of the research program was to bridge the gap between science and practice in water management. This was considered important for two reasons. First, by connecting these two fields, new technologies that are developed will respond better problems in practice. Second, potential technical solutions that have been developed may more easily find their way to practice. Van Kerkhoff and Lebel (2006) distinguish six levels of increasing engagement and power sharing, in cooperation between researchers and practitioners.

This particular research project to a certain extent had elements of all the six types of research that are summarised in table 1.1. However, in general the project is most similar to type 4, integration. In this project, one of the key requirements was interaction with practice. Therefore, a three track parallel research approach was applied. This means the approach was characterised by the parallel development of technical innovations, the study of societal aspects, and strong theory-practice connection in case studies track (De Graaf and Van de Ven, 2006).

In the case studies, innovations with practical applicability were developed. Early in the project information about feasibility was gathered. By implementing innovations in case studies, more information was generated about opportunities and obstacles that enable or constrain, mainstreaming of these innovations. This information was used to improve the innovations in urban water management. Detailed information about the project approach and methodology can be found in the next paragraph and the case study chapters. These chapters also contain a reflection on the use of research results in practice.

Table 1.1 Levels and types of cooperation between practitioners and scientists (Van Kerkhoff and Lebel, 2006)

Level	Type	Role of practitioners	Role of scientists
1	Trickle Down	Consult academic publication	Publish in peer-reviewed journals
2	Translation	Consult published sources	Engage in science communication
3	Participation	Consult scientists directly	Gather and consider practitioner input
4	Integration	Tie research funding to governance, and shared accountability	Funders require specified interaction with practice
5	Negotiation	Recruit researchers to support political agendas	Seek out influential practitioners to further a contested agenda
6	Learning	Recruit researchers to clarify and solve problems	Engage practitioners in iterative processes of research and action

1.4 Research methods

To answer the research questions, different activities were executed in this research. To address research question A1, a literature survey was done to make an overview of theoretical concepts of vulnerability. Based on this overview, vulnerability was defined as a framework that consists of four components. This framework was subsequently applied to water management in two countries, the Netherlands and Japan. Application to water management in the Netherlands

showed that current water management strategies mainly focus on large scale infrastructure rather than local solutions. Examples are given of alternative measures that can be used to develop more comprehensive strategies to reduce the vulnerability of cities. The purpose of the Japan chapter was to develop ideas and illustrate the vulnerability framework with examples from this country (research question A2). The situation in Japan was in particular interesting with regard to climate adaptation of urban water systems. This country has already an extreme climate that causes both floods and droughts. Moreover, similar to the Netherlands, it is a highly urbanized, industrial country with a high percentage of invested capital and population in flood prone areas, including areas under sea level. Thus, the systems that are in place in Japan can provide us with ideas how Dutch urban water systems could function in the future.

1.4.1 Action research in case studies

Two case studies in the city of Heerhugowaard were done to evaluate the technical feasibility of urban water management innovations in practice in order to address research questions B1 and B2. The case studies were also used to develop insights in mechanisms that determine adoption and mainstreaming of technical innovations (research question C1). In the case studies, the author of this thesis actively participated in executing the research in project teams. These teams included other researchers and practitioners from the consortium partners. More detailed information about the project team approach can be found in the case study chapters. The role of the researchers and practitioners in the case studies can be considered the role of reflective practitioner (Schön, 1983). This means they developed insights and critically reflected on their observations while being involved in the practical process of technology application as members of the project team. Critical reflection took place every 6 months in general meetings of the Transition SUW project. In addition, more frequent case study meetings were organised with the case study team. The researchers established a cooperative relation with the practitioners in the case study cities. The insights of this thesis are partly based on active participation of the researchers and practitioner experiences in the case studies. Since this thesis is concerned with developing insight on the application of technical innovations in practice (research questions C1 and C2), active collaboration of the researchers with practitioners was a more suitable method than an external viewpoint as neutral observer.

The method that was applied in the case studies can be considered Participatory Action Research (PAR). Traditional research aims to advance knowledge by developing theories and testing hypotheses. The objective of PAR is not only to advance scientific knowledge, but also to achieve practical objectives such as improving practice (Whyte, 1989). Therefore, to evaluate this research project, the casestudy chapters and the last chapter include a paragraph which describes how the research results were actually used and how an impact on practice was made. These paragraphs were based on the observations of the author of this thesis. The reliability of these observations was improved by reflection of the consortium partners during the general meetings of the Transitions SUW projects. Their comments on case study results and implementation progress were captured in minutes that were approved in the next meeting. Moreover, professional reports were made that were validated by feedback from the case study city representatives before publication. During the preparation of this thesis written questions were sent to case study city representatives in order to ensure the accuracy of the information on official decision making procedures.

According to Brydon-Miller et al. (2003) it is likely that social research remains incompetent if it is executed without developing a collaborative relationship with practitioners. The research

results may be published, but they will remain isolated. The added value of PAR is that the knowledge and expertise of practitioners is used to develop better scientific insights in relevant social problems. In this thesis, collaboration with practitioners contributed to understanding why, and under which circumstances, urban water management innovations are applied or rejected. PAR was therefore a useful research method for the case studies in chapter 4 to 6. Critics of action research claim that the results of action research are subjective and unscientific. The researcher actively takes part in the case study, thus cannot be objective. However, the study topic of this thesis is the dynamic and ever changing social context in which urban water management innovations are applied or rejected. This means that the empirical results that these social case studies produce, cannot be reproduced and can only be partially verified, no matter which method is applied. However, certain mechanisms of technology application that are found in specific situations can have a general relevance. Case studies can therefore contribute in revealing these mechanisms.

A point of criticism of case study research that is often mentioned is that it is not possible to draw general conclusions from a limited number of case studies. However Yin (1984) states that case studies can be used for theory-related analytical generalisation rather than statistical generalisation. A method to generalise and substantiate results from case studies is triangulation or multimethod (Webb et al. 1966). Triangulation is the combined use of multiple scientific methods to study the same phenomenon (Denzin, 1978). More than one method should be applied in the validation process and new insights and better understanding can be developed by combining the strengths of quantitative and qualitative methods (Jick, 1979). This means that normative case study specific findings, in which application of innovations is an important goal, are compared to findings from scientific literature, other case studies and more general studies in order to produce generalisable knowledge. In addition, results should be validated through discussions with scientists and practitioners.

In this thesis, the results of the case studies are further substantiated through comparison with scientific theories, findings from literature, and comparison with the general results of a national survey among urban water management professionals. In these chapters the role of the researcher is external observer and analyst as table 1.2 shows. Professional case study reports in Dutch were produced and discussed with the practitioners. In addition, practitioners reflected on case study findings in general meetings of the Transitions SUW project. Their feedback was collected, captured in minutes, and was used to improve the reports before scientific publications were written.

Table 1.2 Purpose, method and the role of the author for the chapters in this thesis

Chapter	Purpose (Research question)	Methods	Role of author
1	Introduce topic, outline and method	Literature review	External observer and analyst Research designer
2	Develop useful framework for vulnerability Apply framework to Netherlands to evaluate water management strategy Outline alternative options (Research question A1)	Literature review	External observer and analyst
3	Illustrate framework, explore and generate ideas of alternative options using Japan as an example (Research question A2)	Literature review Collaboration with researcher from Japan Fieldtrip	External observer and analyst
4	Proof technical feasibility Collect experiences and observations on application of innovations (Research questions B1, B2 & C1)	Technical feasibility model study Participatory Action Research	Reflective practitioner
5	Proof technical feasibility Collect experiences and observations on application of innovations (Research questions B1, B2 & C1)	Technical feasibility model study Participatory Action Research	Reflective practitioner
6	Explore mainstreaming of innovations by describing the example of floating urbanisation (Research question B1, C1)	Literature review Participatory Action Research	Reflective practitioner
7	Review of theories on application and mainstreaming of innovations. Identify conditions for mainstreaming of innovations (Research question C1)	Literature review	External observer and analyst
8	Present empirical evidence on factors that determine key condition 1: including innovation in spatial planning (Research question C1)	Literature review Case study research Oral interviews	External observer and analyst
9	Measure key condition 2: receptivity of professionals to transformative change Validate results from chapter 8 (Research question C2)	Web based national questionnaire	External observer and analyst
10	Measure key condition 2: receptivity of professionals to urban water management innovations (Research question C2)	Web based national questionnaire	External observer and analyst
11	Draw general conclusions from case studies, literature and national findings (Research question C3)	Synthesis	Analyst and reflective practitioner

1.4.2 Overview of methods

Various methods were used in this research in order to fulfil the research objectives. This thesis aims to combine the advantage of action research, such as better practical applicability, with the objectiveness of traditional research. To determine the main problems and objectives in urban water management, a literature review was done. In order to develop a useful framework for water related vulnerability of urban areas, another literature survey was done on the natural hazards literature. The position of the author in these surveys was external observer and analyst. The Japan chapter in this thesis is an exploration study to generate ideas on urban water management innovations, and to illustrate the vulnerability framework. Chapters 4 and 5 demonstrate the technical feasibility of two urban water management innovations in the Netherlands. These chapters also present observations and reflections of the author on innovation processes that are further tested in part 2 of this thesis. Chapter 6 on floating urbanisation draws on literature and the personal experience of the author in mainstreaming of innovations in the floating urbanisation industry. This chapter is an exploration study to generate ideas on mainstreaming of urban water management innovations.

The mechanisms of mainstreaming of innovations that are found in part 1 of this thesis, are further tested through a literature survey in chapter 7 and a national survey in chapter 9 and 10. Chapters 8-10 aim to validate observations from case studies from part 1 and present empirical evidence on the two key conditions for mainstreaming of urban water management innovations that were drawn from the literature survey in chapter 7.

1.5 Thesis structure

This thesis consists of two parts. The first part is about urban water management innovations to reduce vulnerability of urban areas. The second part of this thesis reflects on social aspects that are relevant to mainstreaming and application of innovations. Drawing on literature a four-component vulnerability framework is introduced and applied on Dutch water management in chapter 2. Examples from Japan to reduce vulnerability are presented in chapter 3. Chapter 4 describes the feasibility of creating a self-supporting water supply for a new urban development in Heerhugowaard, the Netherlands. Chapter 5 examines the technical and economic feasibility of using the urban water system as energy source. Chapter 6 reflects on current developments of using the urban surface water for urbanisation. The chapters 4-6 include a reflection on the process and how research results were used in practice and follow-up projects.

In chapter 7, literature on social theory is used to develop insights in factors that influence mainstreaming of innovations. Chapter 8 presents the results of an innovative planning process that led to mainstreaming of innovations in Rotterdam. In chapter 9, results are discussed of a survey on the receptivity of the Dutch urban water management sector to change the current system. The next chapter draws on the same survey, and specifically discusses practitioner receptivity to the technologies that were described in chapter 4-6. Chapter 11 summarises the results and provides recommendations that could contribute to improve mainstreaming of innovations in urban water management to contribute to cities that are less vulnerable. Figure 1.2 presents the thesis structure.

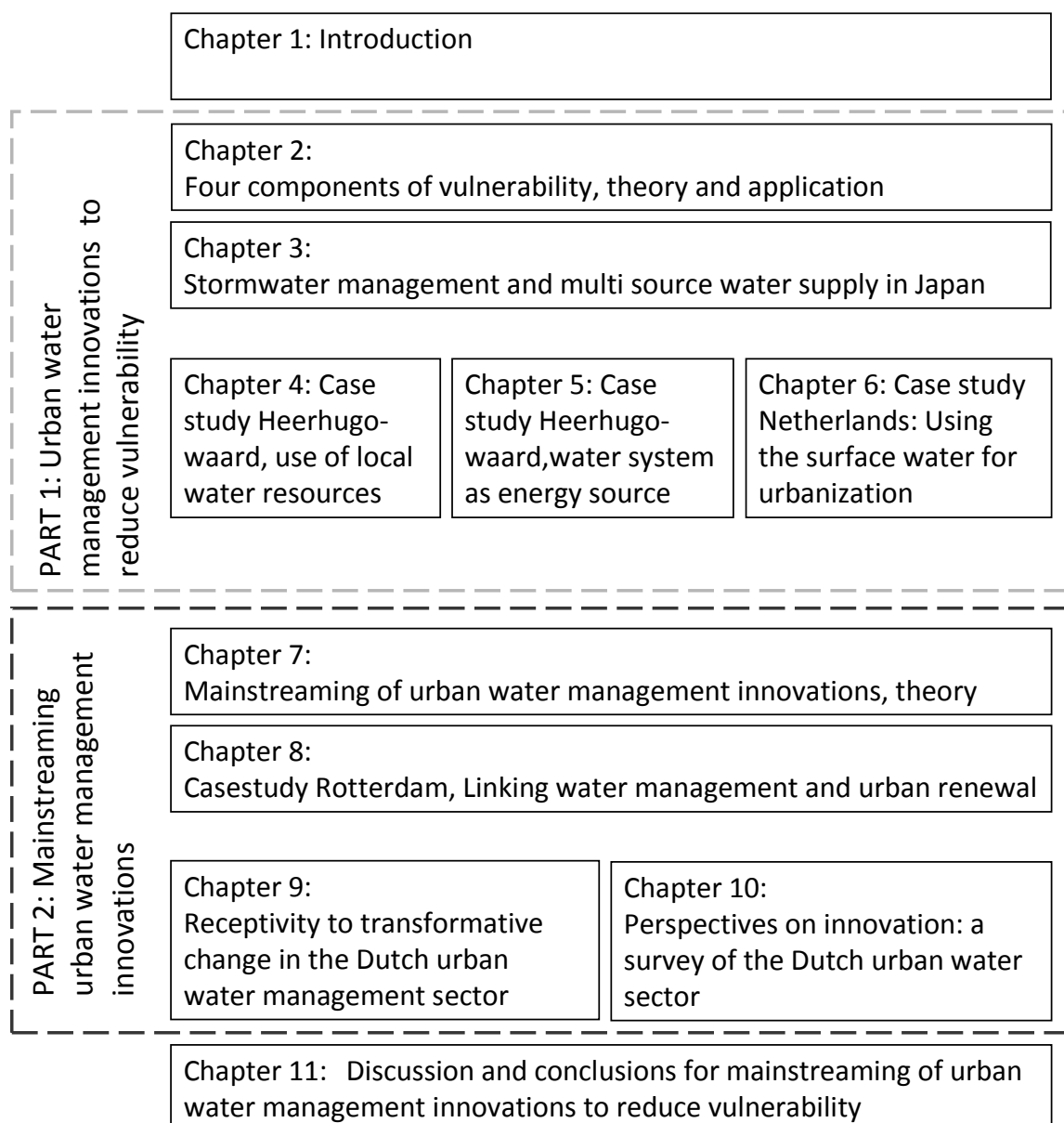


Figure 1.2 Thesis structure

PART 1: URBAN WATER MANAGEMENT INNOVATIONS TO REDUCE
VULNERABILITY OF URBAN AREAS

2 Four components of vulnerability: theory and application²

2.1 Introduction

In chapter 1 of this thesis, the concept of vulnerability was introduced as a theory to develop a more comprehensive understanding of the potential of alternative water management options. This chapter introduces a new theoretical framework of vulnerability. In the Netherlands, both water supply networks and flood defence infrastructure to reduce vulnerability of cities, have a regional or national scale. Therefore the scope of analysis in this chapter is water supply and flood control in the Netherlands. The chapters following this chapter discuss possibilities at city and neighbourhood scale to reduce vulnerability of cities to floods and droughts.

Vulnerability is often defined as the sensitivity of a system to exposure to shocks, stresses and disturbances, or the degree to which a system is susceptible to adverse effects (White, 1974; IPCC, 2001; Turner et al., 2003; Leurs, 2005), or the degree to which a system or unit is likely to experience harm from perturbations or stress (Schiller et al., 2001). The system under consideration can be a community or region. The vulnerability concept is widely used in studies on risks and natural hazards and often also includes social, ecological and political dimensions. Stress and disturbances on a system can be both exogenous and endogenous, ranging from changes in the environment to changes in society.

Some vulnerability approaches consider threats from both inside and outside the considered system, as well as the capacity of the considered system to cope with these threats. Moreover, they consider coupled human-environment systems or the reflexive relation between human society and the environment, instead of only human systems and environmental threats (Fraser et al., 2003; Turner et al., 2003; Leurs, 2005). In the risk glossary of United Nations University, Thywissen (2006) concludes: “vulnerability is a dynamic, intrinsic feature of any community (or household, region, state, infrastructure or any other element at risk) that comprises a multitude of components. The extent to which it is revealed is determined by the severity of the event.”

The concept of vulnerability pays attention to both disturbances and system response. The ability of a system to mitigate stresses and cope with impacts through various strategies is one of the main determinants of system response and system impact (Schiller et al., 2001). According to Blaikie et al. (1994) vulnerability is: “the characteristics of a person or a group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard.” It involves a combination of factors that determine the degree to which someone’s life and livelihood is put at risk by an identifiable event in nature or society. Also other authors (Timmerman, 1981; Bogard, 1989; Dow 1992; Suarez, 2002) link vulnerability to the capacity to act against disturbances and developments. These capacities relate to a complex set of characteristics that include initial well-being, self-protection, group protection, hazard

² This chapter is based on the following publications:

- De Graaf, R.E., F.H.M. van de Ven en N.C. van de Giesen, Alternative water management options to reduce vulnerability for climate change in the Netherlands. *Natural Hazards (in press)*. Available online: <http://www.springerlink.com/content/0921-030X> . DOI 10.1007/s11069-007-9184-4
- De Graaf, R.E., F.H.M. van de Ven and N.C. van de Giesen (2007), The Closed City as a strategy to reduce vulnerability of urban areas for climate change. *Water Science and Technology* 56 (4), 165-173.

preparedness and presence of political networks and institutions (Cannon et al., 2002). A focus limited to perturbations and stresses is insufficient to understand the impact on systems (Turner et al., 2003). Thus, to understand vulnerability requires including the abilities and capacities of the system under consideration. In addition, the capacity to deal with uncertainty is an important factor that determines the vulnerability of a system. A system may be functioning well today, but possible future developments may increase vulnerability if a system is not able to adjust to these developments. Cannon et al. (2002) argue that vulnerability has to include a predictive quality and conceptualise what could occur to a population in case of a future disaster. Therefore, an important aspect of vulnerability is the capacity of communities and societies to adapt to uncertain future developments.

Frameworks that are often used to examine vulnerability take environmental disturbances on exposed human systems into account (Schiller et al., 2001; Turner et al., 2002). In practice however, the exposed system may amplify, attenuate, and create stresses and disturbances. This is illustrated by the fact that a drought can be caused by low river flow, bad water management or both. Low river flow in itself can again be caused by natural variation of weather, or activities such as deforestation or upstream reservoir construction. Flood damage might be caused by high water levels only. However, often it will be a combination of lack of risk awareness, failing warning systems, lacking or non functioning emergency plans, insufficient maintenance of flood defence, urbanisation in flood prone areas and high water levels that cause flood damage and determine its severity.

Also in other complex system such as ecosystems there is a connection between vulnerability of the system and human practices. Environmental management practices can decrease coping capacity of ecosystems and make them more vulnerable to exogenous forces such as hurricanes and fires (Scheffer et al., 2001). These examples illustrate that we are dealing with coupled human and environmental systems and that an artificial distinction between environmental hazards and human vulnerability is not sufficient to understand complex interactions between human and environmental systems.

2.2 Four components of vulnerability

The literature review in the introduction section shows that vulnerability is determined by the ability to build a threshold against disturbances. Moreover, most reviewed definitions include the ability to cope with disturbances as a determining factor of vulnerability. Some approaches also take the capacity to recover from disturbances into account and include future elements in the approach towards vulnerability (Blaikie et al., 1994; Cannon et al., 2002; Turner et al., 2003).

Vulnerability is therefore defined in this thesis as a combination of four aforementioned components: threshold capacity, coping capacity, recovery capacity and adaptive capacity. This vulnerability framework will be further elaborated and will be used to evaluate flood control and water supply strategies. These are two important components of current water management practice in the Netherlands. Subsequently, the vulnerability framework is used to identify alternative options in water management. Table 2.1 illustrates the four capacities framework.

2.2.1 Threshold capacity

Threshold capacity is the ability of a society to build up a threshold against variation in order to prevent damage. In flood risk management, examples are building river dikes and increasing flow capacity to set a threshold against high river flow. In case of water supply, examples are constructing storage reservoirs to increase the damage threshold by preventing loss of service in

case of droughts. The objective of building threshold capacity is prevention of damage. The time horizon lies in the past; past disaster experiences of society are the guiding principle to determine the height of the threshold. In the Netherlands, for ages dikes were constructed that had the same height as the highest experienced flood. The dimensions of a water resources reservoir are determined by historic droughts and water use levels. As a result, the uncertainty of the height of the threshold is relatively low. The ability of a society to build, operate and maintain threshold capacity is determined by its environmental resources and its social, institutional, technical and economic abilities. In the Netherlands, this is relatively well organised. The responsibility of maintenance of flood defence and water delivery infrastructure is clear. Waterboards are responsible for maintaining flood defence, water utility companies are responsible for safe and efficient delivery of drinking water.

Table 2.1 Description of type, hazard frequency, time orientation, uncertainty and responsibility of the four components of the vulnerability framework that is introduced in this thesis.

Component	Type	Frequency of hazard	Time orientation	Uncertainty of hazard magnitude	Responsibility
Threshold Capacity	Damage Prevention	High	Day- to day practice, Past as guideline	Low	Clear
Coping Capacity	Damage Reduction	Medium	During emergency	Low	Not clear
Recovery Capacity	Damage Reaction	Medium	After emergency	Low	Not clear
Adaptive Capacity	Damage Anticipation	Low	Future, envisioning, pro-active change	High	Undefined

2.2.2 Coping capacity

Coping capacity is the capacity of society to reduce damage in case of a disturbance that exceeds the damage threshold. For flood management coping capacity of society is determined by the presence of effective emergency and evacuation plans, the availability of damage reducing measures, a communication plan to create risk awareness among inhabitants, and a clear organisational structure and responsibility for disaster management. For water supply, the availability of emergency and backup water facilities that can be used in case of droughts and disasters, are important determinants of coping capacity. The objective of developing coping capacity is reduction of damage, either by reducing flood impacts or by reducing loss of service for water supply. The time orientation is instantaneous, because in case of emergencies, only 'here and now' is important. The uncertainty is low because the magnitude of the hazard is clear at the time society has to deal with it. Also for coping capacity the ability of a society to build, operate and maintain it is determined by its social, institutional, technical and economic abilities.

There is a large range of coping capacity options. In the Netherlands threshold exceeding events for water management do not occur frequently. This may be an explanation why it is not clear who is responsible for damage reduction in case of emergencies. Multiple actors such as fire fighters, waterboards, municipalities, and other government agencies are involved. This is illustrated by a national government report on critical infrastructures that identifies lack of clarity, lack of knowledge and lack of coordination between stakeholders as the three most important problems (MBZ, 2005).

2.2.3 Recovery capacity

The recovery capacity is the third component and refers to the capacity of a society to recover to the same or to an equivalent state as before the emergency. For flood control, it is the capacity of a flooded area to reconstruct buildings, infrastructure and dikes. For water supply, it is the capacity to achieve a functioning water supply and sanitation system again. The objective of developing and increasing recovery capacity is to quickly and effectively respond after a disaster. The time horizon is instantaneous right after the disaster but will change gradually towards a focus on the future. Although economical damage estimates may be difficult, the uncertainty of the hazard magnitude will be relatively low because the effects will still be noticeable. The economic capacity of the country to finance the reconstruction determines the recovery success to a large extent. However, institutional ability and technical knowledge are also important. A society that is able to recover from impacts of hazards will be less vulnerable for these hazards. Recovery time may range from weeks to decades, depending on the spatial scale and disaster magnitude. Recovering from the Katrina hurricane in New Orleans will take years (Kates et al., 2006). Although in the Netherlands it is clear who is responsible for reinstalling the flood control and water delivery infrastructure, it is not entirely clear who is financially responsible for compensating the hazard impacts (Kok, 1996). In the past, the Dutch government often refunded flood damage to house owners. However, also people themselves or insurance companies could be responsible, in particular in areas that are not protected by dikes.

2.2.4 Adaptive capacity

Adaptive capacity is the capacity of a society to anticipate on uncertain future developments. This includes catastrophic, not frequently occurring disturbances like extreme floods and severe droughts. The time orientation of adaptive capacity lies in the future. Although a system may be functioning well at present, human and environmental developments, both from inside or outside the considered system, can put a system under strain and threaten its future functioning. Examples are climate change, population growth, and urbanisation. Central to the importance of adaptive capacity is the acknowledgement that these processes may be influenced but cannot be predicted, engineered or controlled. Because the system cannot be optimized for a known situation in the future, building adaptive capacity by anticipating on uncertainty is important. Another reason to develop adaptive capacity is the acceptance that dealing with these uncertain future developments might require more than improving threshold, coping and recovery capacity. From this perspective, developing adaptive capacity is a form of the precautionary principle. Without adaptive capacity, society will try to recover from climate change impacts until it is no longer possible.

Preventing a technical lock in pattern and securing diversity by keeping options open for future development contributes to adaptive capacity (Folke et al., 2002; Pahl-Wostl, 2007). New technologies and innovations will be developed in the future. Adaptive infrastructure means that

these options can be incorporated in large technical water management systems. Without adaptive capacity, promising new technologies that are not compatible with the current system will be excluded and opportunities will be missed. Water management systems should therefore be flexible and reversible to allow for future changes to be made. As such, adaptive capacity improves the freedom of future generations to implement alternative options. The role of engineers is to make as many options available to society as possible and put these options in relation to the objectives of society (Harremoës, 1997). Technologies reflect values of society; they are socially constructed (e.g. Bijker, 2006). Adaptive capacity is therefore also a necessity for ethical reasons. Adaptive capacity offers freedom to future generations because it enables them to include technologies in water management infrastructure that reflect their values.

For flood control, the problem of adapting to uncertain future developments can be illustrated by an example of land use. Although future risks from river or sea floods are unknown, land use decisions that determine future vulnerability are presently being taken. For water supply, a good example is salt water intrusion. The sea level and river discharge in 2050 are unknown; hence also the future problem of salt water intrusion into the Dutch river delta is unknown. However, the consequences of decisions to construct inlets for drinking water production points in this delta exceed the horizon of reliable climate predictions. The Dutch drinking water companies have not yet implemented a strategic vision how to deal with climate change (Kiwa, 2006a).

The objective of developing adaptive capacity is to anticipate on future developments and impacts by constructing a robust living and working environment. The uncertainty about the nature and magnitude of future hazards and impacts is high and the frequency of occurrence is low. The capacity to adapt to these uncertain developments also determines the vulnerability of a system. Although the exact size and nature of changes are unknown, solutions will have to be developed for long time horizons and financial and spatial reservations to allow for adaptations will have to be made. The IPCC (2001) presents many options available for society to increase its adaptive capacity, varying from technical options to insurance policy and communication strategies. The range and variety of possible adaptive options is large and the number of involved organisations in the adaptive capacity determinants is also large. Consequently, there is no clear picture about who is responsible for strengthening adaptive capacity.

2.2.5 Complex interactions between vulnerability components

It is a societal objective to become less vulnerable to all kinds of hazards, long term and short term. However, to decrease vulnerability is a complex task. Vulnerability components are highly connected. Consequently, increasing one vulnerability component could decrease one or more of the other components resulting in higher, rather than reduced vulnerability. The connection between vulnerability components is illustrated. Figure 2.1 presents a conceptual damage return period graph. As a result of dike construction or reservoir construction, environmental variations with low return periods will cause no damage. This is the threshold domain in Figure 2.1.

Even if thresholds have been built, there will be some occasions when the threshold will be exceeded. Then, coping with hazard impacts and recovering from them is necessary. This is the coping and recovery domain in which damage reduction is the prime goal. Finally, there are very unlikely events with very high return periods where the expected damage is that extreme that recovery is neither feasible nor possible. These types of occasions we want to prevent by adapting. Therefore, this is the adaptive domain. However, adaptive capacity is more than what is illustrated in figure 2.1. It also includes the capacity to deal with future changes in figure 2.1 that

are still uncertain, due to climate change and other developments. For instance, by more frequent storms, flood damage might occur more frequently. If the adaptive capacity is high society will be able to anticipate on this situation. Less damage will occur than in case there is only limited adaptive capacity and costly emergency and recovery measures will have to be taken.

The conceptual damage-return period graph in figure 2.1 illustrates that by increasing only the threshold domain, for instance by building higher and stronger dikes for flood control or by building reservoirs for water resources, the coping and recovery domain becomes smaller. Increasing threshold capacity may decrease the risk awareness of citizens and reduce their experience to recover from flooding. An approach that only focuses on increasing threshold capacity results in a system that is increasingly vulnerable to rarely occurring disasters. Disasters that cause damage will occur less frequently, but the ones that do occur will cause more damage. Consequently, for a complete vulnerability reducing strategy, attention should be paid to all components and domains of vulnerability.

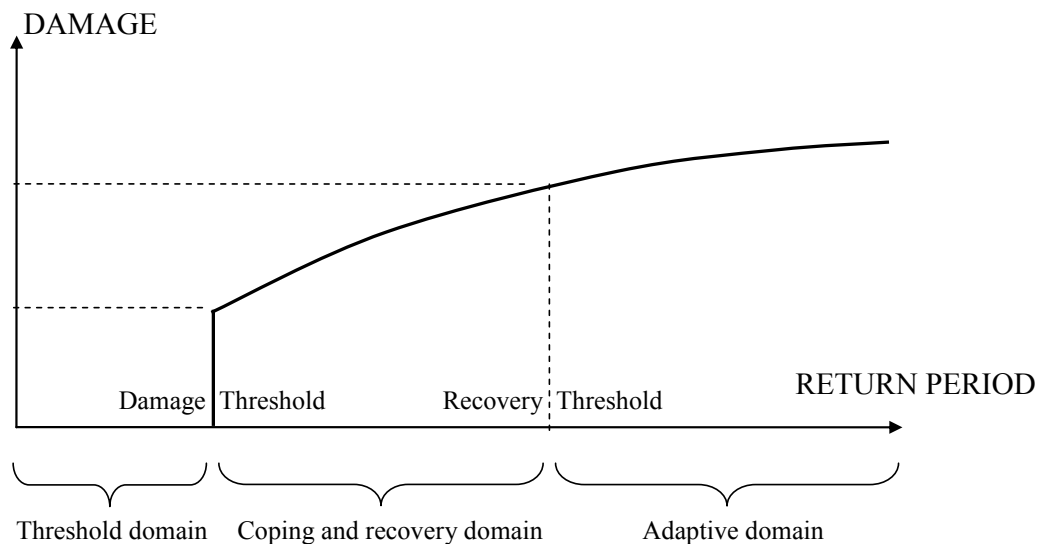


Figure 2.1 The four components and three domains of the vulnerability framework illustrated by a damage return period graph. The three domains are interrelated, changes in one domain affect the other domains, resulting in an overall change in vulnerability

2.3 The Netherlands: vulnerability of flood defence

Evaluation of flood defence in the Netherlands is founded on safety design standards that are based on a probability of exceedance of a certain water level. These safety design standards are the threshold capacity of society against flooding. In the densely populated western part of the country, the design return period (T) is highest, $T=10,000$ years. In the other parts of the country, the design return period is lower, $T=4000$ years, $T=2,500$ years and $T=1,250$. From these design standards, water levels have been derived that have been used to determine the height of the dikes (Ministerie van Verkeer en Waterstaat, 2005). Next to coastal and river flooding, guidelines have been made for pluvial flooding (NBW, 2003). For grassland the return period is $T=10$ years, for arable land $T=25$ years, for horticulture $T=50$ years and for urban areas $T=100$ years.

Flood disasters of the past have led to a process of continuously increasing the height and strength of dikes. Because of this process, the damage threshold return period has become very high. The damage threshold is an average statistical return period of the design water level. In The Flood Risks and Safety in the Netherlands project Floris (Ministerie van Verkeer en Waterstaat, 2005), the expected damage of dike failures for multiple locations in multiple scenarios has been calculated. Expected damage figures range from € 1.9 billion in case of a single dike failure in Scheveningen up to € 37.2 billion in case of three simultaneous sea dike failures. The number of expected fatalities range from 100 in case of an expected flood, one single dike failure and organised evacuation, up to 5090 in case of three simultaneous dike failures, an unexpected flood and no evacuation (Jonkman, 2007). The annual probability of flooding is much higher than the design standards, ranging from $T=2,500$ years in Zuid-Holland to $T=100$ years in the rivers region. This is due to the fact that dike failures often take place by other mechanisms than dike overtopping in case of high water levels.

Heavily urbanised areas will be increasingly vulnerable for natural hazards (Mitchell, 1999). The estimated amount of required new houses in the Netherlands in the period until 2030 varies from 1 million to 1.5 million in various scenarios (VROM et al., 2005). In the Netherlands, urbanisation, continued land subsidence and sea level rise will result in increased flood risk vulnerability. This will result in an increasingly densely populated, increasingly low-lying area under an increasing sea level. Current national strategies are still mainly focused on improving threshold capacity. A good example is the recent advice of the Delta Commission on flood protection and climate change in the Netherlands (Committee Veerman, 2008) to increase threshold capacity tenfold. Although the report also contains adaptive elements such as a long time horizon and integration with spatial planning, the report strengthens a sense of absolute security. The Veerman report has been used as input to develop the National Waterplan (Ministerie van Verkeer en Waterstaat, 2008a). This plan mentions damage prevention as the main priority. Out of the six water safety measures categories that are presented in the report, four categories aim to improve threshold capacity, one improves coping capacity and one improves adaptive capacity. No recovery capacity improvement measures are mentioned.

Increasing damage thresholds by further rising and strengthening of dikes, will not give absolute certainty that future disastrous flooding events will have no negative impacts. On the contrary, absolute security is impossible and statistically there will always be occasions where the threshold will be exceeded and where coping and recovering is necessary. Adaptive measures to counter uncertain changes to both more variability of the water level and gradual changes in the mean water level are needed.

2.4 The Netherlands: vulnerability of water supply

In the western part of the Netherlands, urban areas depend on external river water resources for their water supply. In the eastern part, mainly ground water is used. In this section vulnerability of water resources in the Netherlands is analyzed by addressing possible future developments.

In the Netherlands, buffer reservoirs have been constructed by the water utilities to secure threshold capacity against disruption of source water inlet due to droughts and water pollution. The water utilities that use the dunes for infiltration of river water have strategic dune fresh water storage. However, this storage can only partially be used during droughts to prevent damage to nature areas and to prevent salt water intrusion. Table 2.2 presents the threshold capacity for the drinking water companies in the western part of the Netherlands that use surface water as a source for drinking water production.

Table 2.2 Threshold capacity of water utilities in the western part of the Netherlands. Storage capacity is used to prevent loss of service during disruption of source water availability, due to droughts or insufficient water quality (Source: KWR, 2008).

Water utility	Inlet point	Type of storage	Threshold capacity
DZH	Brakel (afgedamde Maas)	Storage reservoir	2-3 weeks
Evides	Gat van de Kerksloot (Amer)	Storage reservoir	2-3 months
Waternet	Nieuwegein (Lekkanaal)	Dune infiltration	2-3 weeks
PWN	Andijk (Ijsselmeer)	Storage reservoir	4-6 days
Evides	Scheelhoek (Haringvliet)	Dune infiltration	2-4 weeks
Oasen	Multiple locations	River bank filtration	none

The vulnerability of Dutch drinking water supply increases due to climate change. Recent climate scenarios of the Royal Netherlands Meteorological Institute are presented in Table 2.3. Detailed information about the climate change scenarios for the Netherlands can be found in the scientific report (KNMI, 2006). Two main driving forces were selected to construct the scenarios by running combined simulations of both General Circulation Models and a Regional Climate Model. The first driving force is global temperature change. For the low (G) scenarios, global temperature increase is +1 °C in 2050 and +2 °C in 2100. For the high (W) scenarios, global temperature increase is +2 °C in 2050 and +4 °C in 2100. The second driving force is the change of the mean seasonal regional atmospheric circulation. This driving force determines the Dutch regional climate to a large extent. Predominantly western atmospheric circulation, very similar to the current situation, results in a relatively mild and temperate climate whereas a change towards more eastern circulation conditions would change the regional climate into a more continental climate with dry and hot summers. In the + scenarios (G+ and W+), a strong decrease of the western atmospheric circulation takes place in summer. As a result, warm, dry continental air is transported to the region. In winter, the + scenarios adopt a slight increase in western circulation.

For the other two scenarios (G and W), in summer a small increase of western circulation flow takes place. In winter, there is no change compared to the current situation. The four scenarios were designed to span a large part of possible futures in order to deal with the uncertainty of future changes. Based on current insights that are derived from current climate models, the probability that the future climate will be within the range of the four scenarios is estimated at 80% (KNMI, 2006). Therefore, there is not a 'most likely' scenario and all four scenarios should be used to develop water management options.

In the + scenarios summer droughts will occur more frequently, resulting from lower precipitation and higher evaporation. The resulting water shortages can be partly covered by a higher precipitation amount in winter. In that case, however, water storage capacity should be available. In the Netherlands, limited terrain level differences are available for water storage and the current water management practice is characterised by artificially maintaining water levels at fixed targets in polder water systems, thus limiting the potential for water storage. In the other two scenarios (G and W), the expected increase in evaporation is only little higher than the increase in precipitation. However, even in case of these two scenarios, the frequency of droughts may increase. A higher temperature will probably lead to rising water use for agricultural, energy (cooling) and residential purposes (Van Drunen, 2006). A higher sea level will lead to increased seepage of brackish groundwater into the Dutch polders under sea level which will in its turn

increase the demand for fresh water to flush the polder water systems (Oude Essink, 2001; De Bruin and Schultz, 2003). Unfortunately, the exact size of these effects of climate change on water management in the Netherlands is not known. More research, well outside the framework of this study, is needed to quantify these effects more precisely.

Table 2.3 Four scenarios for climate change in the Netherlands in 2050 relative to 1990. Two driving forces were selected to construct the scenarios, the change in the atmospheric circulation pattern and the global temperature change. In the + scenarios there is a strong change in the atmospheric circulation pattern. In the other scenarios this change is weak. The G scenarios have a relatively small global temperature increase, the W scenarios have a higher global temperature increase (KNMI, 2006).

2050		G	G+	W	W+
Global temperature increase in 2050		+1°C	+1°C	+2°C	+2°C
Change of atmospheric circulation		Weak	Strong	Weak	Strong
Winter	Mean temperature	+0.9 °C	+1.1 °C	+1.8 °C	+2.3 °C
	Precipitation	+4%	+7%	+7%	+14%
Summer	Mean temperature	+0.9 °C	+1.4 °C	+1.7 °C	+2.8 °C
	Precipitation	+3%	-10%	+6%	-19%
	Potential Evaporation	+3.4%	+7.6%	+6.8%	+15.2%
	Daily cumulative precipitation ($\Gamma=10$ years)	+13%	+5%	+27%	+10%
Sea level	Absolute increase	0.15-0.25 m	0.15-0.25 m	0.20-0.35 m	0.20-0.35 m

In addition to internal water resources such as precipitation, also external water resources will be affected by climate change. At present, large rivers, in particular the Rhine, generate a relative constant supply of water to the Netherlands during summer. This constant flow consists for a considerable part of snowmelt from its Alpine catchment. Melting off peaks usually occur in spring and early summer (Van de Ven, 1996). However, the mean temperature in Europe is expected to increase which will generate an earlier snowmelt that will increase the possibilities of water shortages in summer. The expected summer discharge of the Rhine will decrease with 10% in an average climate scenario and even 60% in a dry scenario (NMP, 2004). As mentioned, another effect of climate change is sea level rise, this effect, combined with land subsidence and lower river discharge in summer can result in problems with salinity. Consequently, water intake

from rivers in delta areas will become more difficult and the chance of water shortage will increase. The exceedance frequency of a year with very high salinity in the delta, increases with 80% in an average climate scenario (RIZA, 2005). As a result, water inlets will have to be closed more often. The current strategies to address these challenges are focused on optimizing the current system by improving threshold capacity. In the Nation Vision on the Waterchain (VROM, 2003) local water resources are not mentioned. In the Household Water Policy Statement (Van Geel, 2003) the national government has adopted a restrictive policy for alternative water sources. The position papers of the Dutch Association of Dutch Water Companies Vewin are primarily focused on efficiency improvement. The position paper on climate adaptation is focused on protecting current sources rather than developing new sources (Vewin, 2009). Only recently, the water utilities have been appointed as partners in crisis management by the minister of Ministry of the Interior (Vewin, 2009).

All mentioned developments in this chapter, summer river discharge, precipitation, and sea level rise are characterised by wide margins of uncertainty. At present, little is known about the specific effects of climate change on water management in the Netherlands. This is in particular the case for urban water management. However, the size of changes and precise effects may be uncertain, the direction of change is not. All mentioned developments and effects in this chapter contribute to more frequently occurring droughts in the future (RIZA, 2005). Therefore, cities that continue to depend only on one single external water resource, either river water resources or external groundwater resources, will be increasingly vulnerable to droughts. In addition heavy rainstorms are expected more frequently which will result in more pluvial flooding with the existing urban drainage infrastructure.

2.5 Towards reduced vulnerability

It is important for urban areas in general, to become less vulnerable to flooding and droughts. For that purpose, all four components of vulnerability should be taken into account. Not only strengthening and raising dikes, but also investing in risk communication, emergency plans, and experimenting with other modes of urbanisation. Not only focusing on better and more efficient water storage and delivery infrastructure but also on demand management, water saving technology and decentralised, more flexible water supply. This adds diversity to the options society has available to face uncertain future developments and disturbances. In many fields of science, strengthening diversity as vulnerability reducing measure has been advocated. Examples are ecology, corporate management sciences, public management sciences and economics.

2.5.1 Lessons from other fields of science

According to the Panarchy theory, human and natural systems are more capable to cope with and adjust to shocks and disturbances if they are more diverse (Gunderson and Holling, 2001). The Panarchy theory was developed by landscape ecologists that applied the theory to a broader context as well by studying social systems. However, also in other scientific disciplines diversity as a strategy to reduce risks under conditions is mentioned.

In economics for instance, portfolio management is used to reduce risk to investments for future uncertain disturbances. By building a portfolio of investments with a low mutual correlation the investor minimises effects of disturbances on his returns. Fraser et al. (2005) have shown that applying the concept of financial portfolio management offers insight in reducing the vulnerability of urban supply chains, in their case food supply of urban areas.

In corporate management sciences, the interlinkages between diversity, vulnerability and supply chains of resources and products are studied as well. In *The Resilient Enterprise*, Sheffi (2005) shows that diversity and flexibility in the supply chain of companies, can give them competitive advantages over their rivals in case of unanticipated disturbances such as fires, strikes or terrorists attacks. More diversity leads to a company that is less vulnerable to uncertain future disturbances. The recovery capacity of a company to bounce back after a disturbing event is enhanced by building in redundancy and flexibility.

In public management sciences, diversity is also an important aspect. An approach to deal with complex problems under conditions of high uncertainty is transition management (Rotmans, 2003), which focuses on realizing a societal transformation to decrease vulnerability. Transitions typically take a generation or more to develop. Transition experiments are small scale experiments aimed at sustainable system innovation. For highly complex problems, by definition it is impossible to develop the solution beforehand (De Bruijn et al., 2002). After all, the effects of climate change are uncertain and so are the available future technologies and their consequences. Therefore, experimenting and learning by doing is necessary. By executing transition experiments, learning with new modes of supply, takes place rather than optimizing existing infrastructure. The information and experience gained by these experiments provide diversity to society and are used to improve other experiments. This improves the adaptive capacity.

Current vulnerability reducing strategies of water supply companies mainly focus on threshold increasing measures and little on coping capacity measures. Examples of threshold capacity measures are constructing improved water storage and delivery infrastructure. This is not a complete vulnerability strategy. This chapter identifies options to add coping, recovery and adaptive components to current strategies in order to achieve a complete vulnerability strategy. To quantify the effectiveness of these options to reduce vulnerability for climate change is not yet possible because (1) there is no information yet about the specific impacts of climate change on local urban water systems in the Netherlands and (2) information about the effectiveness of new local concepts for water supply and flood control is lacking since most research is aimed at optimizing the current water management infrastructure. Therefore, within the scope of this chapter, vulnerability reducing options will be discussed by using the vulnerability framework to describe alternative measures. Some of these measures will be further studied in chapters 3 and 4. Based on the four component vulnerability framework, Table 2.4 gives examples of vulnerability decreasing measures for water supply and flood control. For a comprehensive overview of more than 150 measures to improve the climate robustness of cities, the reader is referred to Van de Ven et al. (2008).

2.5.2 Reducing vulnerability to flooding

Section 2.3 demonstrated that in flood control, the emphasis is on increasing threshold capacity to reduce vulnerability. Examples are constructing higher and stronger dikes and increasing the discharge capacity of rivers. As figure 2.2 illustrates, this could lead to a lock in situation in which urbanisation leads to higher dikes which leads to more urbanisation, which leads to increased flood risk, which leads to higher dikes. The result is that disasters occur less frequently, however if they occur the effects are more disastrous. Geldof (2001) calls this mechanism societal rebound. Flood control measures decrease flood risk. Society potentially reacts on the decreased flood risk by starting more activities in this area which partially cancels out the effect of flood control measures.

Instead of this lock in strategy, urbanisation strategies could be developed that include all four capacities to reduce vulnerability. Timely flood warning and improving risk communication would make residents better prepared to cope with flooding. The current potential for evacuation in the Netherlands is limited, however, this would be different in the future if there would be more local shelter and emergency refuge areas. Flood proof buildings in urban areas reduce damage during floods and can function as shelter.

In addition to securing threshold capacity, improving recovery capacity could be done by insuring flood risks and disaster funds. Recovery plans and recovery training may contribute to faster and better recovery. This will reduce the overall vulnerability of an urban area. Adaptive measures, finally, would for example be experimenting with other modes of urbanisation that do not or less, increase flood risk. Such modes of urbanisation are wetproofing and dryproofing of buildings, building on mounds, building on piles or constructing floating cities (Van de Ven et al., 2008). Adaptive measures would have two mitigating effects: 1) buildings and the urban infrastructures are more resistant against the impacts of flooding and 2) local refuge areas are created that provide shelter for residents during floods. Flexible and reversible infrastructures allow for the incorporation of new technologies that will be developed in the future. For this purpose, the development of multiple modes of flood proof urbanisation is required. Reservation of space for water retention improves the future ability to adapt to more frequent flooding and droughts. This measure requires the integration of water management and spatial planning. A broad range of actors such as insurance companies, construction companies, municipalities, and residents should be involved to successfully develop a complete vulnerability strategy. It is needed to start an explorative learning process by experimenting with more climate robust concepts of urbanisation, in order to increase the options of society in face of uncertain future developments.

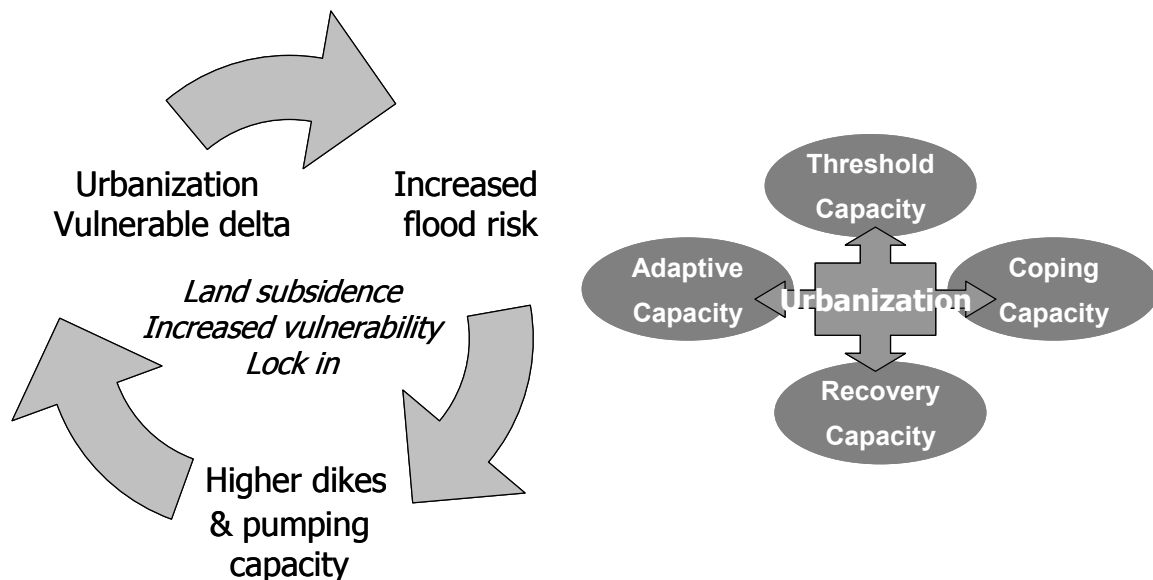


Figure 2.2 Only increasing threshold capacity could create a lock in that leads to increased vulnerability. Instead, all four capacities of the vulnerability framework should be addressed.

Table 2.4 Examples of vulnerability decreasing options for water supply and flood control classified according to the four components of vulnerability

	Water supply	Flood Control
Threshold capacity	<ul style="list-style-type: none"> -More water storage -More efficient water delivery infrastructure - Demand management, e.g. permanent water restrictions - Use of multiple sources as part of day-to-day water supply 	<ul style="list-style-type: none"> - Higher and stronger dikes - Increased river capacity - Real time control
Coping capacity	<ul style="list-style-type: none"> - Emergency plans, drought forecasting - Backup water supply facilities - Water restrictions during droughts - Use of multiple sources during droughts 	<ul style="list-style-type: none"> -Emergency plans, flood forecasting and timely flood warning -Improved communication of risks to inhabitants - Flood proof urbanisation - Emergency water storage reservoirs
Recovery capacity	<ul style="list-style-type: none"> - Recovery planning and training - Disaster funds - Use of multiple sources as recovery 	<ul style="list-style-type: none"> - Insurance - Recovery planning and training - Disaster funds
Adaptive capacity	<ul style="list-style-type: none"> - Flexible and reversible water supply infrastructure - Start a social learning process by developing experience and knowledge of multiple sources to build diversity 	<ul style="list-style-type: none"> -Experimenting with other modes of urbanisation to build diversity - Flexible and reversible flood control infrastructure - Reservation of space by integrating water management and spatial planning

2.5.3 Reducing vulnerability to droughts

The expected changes indicate more frequently occurring dry spells, a higher sea level and lower river discharge. The probability increases that conventional drinking water production by centralised drinking water treatment plants in the Dutch river delta will be hindered. In such a situation, water use restrictions, low water reservoir levels and decreasing drinking water quality will occur. Not only residential water use will be affected, but also industry, shipping, electricity plants and agriculture. This will result in huge economic losses. In 1976, the driest year in recent history, the total estimated economic damage was multiple billions of Euros and disruption of drinking water supply occurred (Riza, 2005). The statistical return period of the 1976 drought is 100 years, however in 2050, the return period of a comparable dry year is estimated to be 45 to 60 years (Riza, 2005).

During a drought such as 1976, the measures indicated in table 2.4 would mitigate damage. Examples of measures that increase threshold capacity are the construction of large water reservoirs and more efficient water delivery infrastructures. These measures provide a threshold for society against environmental variation. Also structural water restrictions can be regarded as threshold capacity measures because they permanently contribute to preventing the effects of droughts.

Coping capacity measures are backup water supply and the use of alternative water sources during droughts. In urban areas, local water resources such as recycling of effluent and stormwater could compensate for the lack of river water resources. Stormwater, for instance, is a relatively clean source that is not yet used for drinking water production. This source has the potential to make urban districts self-supporting with regard to their water supply. Currently, stormwater is mostly converted to wastewater in combined sewer systems. By using local resources in addition to centralised supply, urban districts in the country would not depend on one single external source but instead use a combination of local stormwater, river water, recycled effluent and regional surface water. Emergency plans and backup emergency facilities, such as water trucks and backup water supply points in each city would also reduce damage and secure water supply for the population. Moreover, recovery to a normal water supply condition would take place more quickly as cities would not be depending on external water resources only. An example is fit-for-purpose water use. High quality drinking water is then only used for purposes that require high quality. For other functions, such as toilet flushing other water sources are used such as recycled effluent. The experience and knowledge to deal with the risks of local water sources are currently lacking. Some risks of local water resources will be discussed in chapter 4. The required societal knowledge and experience can be built by small scale projects with other modes of supply. This enables society to switch to alternative local sources if conventional external sources are scarce.

The drought example illustrates the importance of building experience with new modes of water supply. Our current large scale, centralised water supply may be optimal during normal supply and demand conditions, however, the system is not necessarily the best choice during droughts and has a low capacity to adapt due to sunk costs, vested interests, fixed assets and user expectations. Chapter 7 will discuss this topic in more detail. A possible way to improve the adaptive capacity is to start a social learning process by developing experience and knowledge of multiple sources.

2.6 Conclusion

Based on a review of scientific literature, this chapter demonstrated that vulnerability is determined by threshold capacity, coping capacity, recovery capacity and adaptive capacity. Evaluation of the main Dutch national water supply and flood control policy documents shows that current strategies to reduce vulnerability are focused on improving threshold capacity and hardly include measures to increase coping capacity, recovery capacity and adaptive capacity. An approach that only focuses on increasing threshold capacity results in a system that is increasingly vulnerable to rarely occurring disasters. Therefore, the current national water policy cannot be regarded as a sufficient strategy to reduce vulnerability of cities to floods and drought. It should be supplemented with measures to improve coping capacity, recovery capacity and adaptive capacity. Developing comprehensive strategies that address all four components of the vulnerability framework is essential if we accept that the environment cannot completely be controlled, we want to keep options open for future development, and that we are facing

uncertainties with regard to the impacts of urbanisation, climate change, demographic and economic developments on water systems.

In this chapter, the vulnerability framework was used to identify alternative water management options that contribute to all four capacities of the vulnerability instead of threshold capacity only. Emergency plans, floodproof constructions, and improved risk communication are possible coping capacity improvement measures. Multi-source water supply contributes to an increased coping and recovering capacity of water supply systems during droughts. Insuring flood risks or setting up disaster compensation funds could increase recovery capacity. Demonstration projects to increase the diversity of available options, flexible and reversible infrastructure, and integration of water management and spatial planning are examples of measures that increase adaptive capacity.

High amounts of invested capacity in low-lying areas and a high threshold capacity have made the Netherlands highly vulnerable to floods with a high return period. Increasing damage thresholds by further rising and strengthening of dikes will not give absolute certainty that future disastrous flooding events will have no negative impacts. On the contrary, absolute security is impossible and statistically there will always be occasions where the threshold will be exceeded and where coping and recovering is necessary. Also, because rising dikes does not prevent pluvial flooding.

At present, little is known about the specific effects of climate change on water management in the Netherlands. However, the size of changes and precise effects may be uncertain, the direction of change is not. All mentioned developments and effects in this chapter contribute to more frequently occurring droughts in the future. Therefore, cities that continue to depend only on one single external water resource, either river water resources or external groundwater resources, will be increasingly vulnerable to droughts.

3 Stormwater management and multi source water supply in Japan: Innovative approaches to reduce vulnerability³

3.1 Introduction

Chapter 2 introduced the four component vulnerability framework. The chapter demonstrated that in order to reduce vulnerability of urban areas, it is necessary to include all four components of the vulnerability framework in developing water management strategies. Chapter 2 also provided examples of water management options that contribute to coping capacity, recovery capacity and adaptive capacity. One purpose of this chapter is exploration of urban water management innovations in order to develop ideas of alternative options in urban water management. In this chapter, examples of urban water management innovations from Japan are described. Water management in Japan is in particular interesting with regard to climate adaptation. This country already has an extreme climate. Moreover, similar to the Netherlands, it is a highly urbanized, industrial country with a high percentage of invested capital and population in flood prone areas, including areas under sea level. Thus, the systems that are in place in Japan can provide us with ideas how Dutch urban water systems could function in the future.

Japanese water management measures are classified according to the vulnerability framework of chapter 2. Some measures may qualify for more than one component of the vulnerability framework. For instance, some measures contribute to the reduction of damage during a disaster but also contribute to better recovery afterwards. These measures are in particular interesting for developing a comprehensive strategy to reduce vulnerability. In case certain measures contribute to more components of the framework, it is mentioned separately in this chapter.

The extreme geography and climate of Japan has made the country vulnerable to natural hazards. Because of intensive rainfall, flooding occurs frequently. Table 3.1 presents the design precipitation with a 10 year return period in the Netherlands and Japan. Flood problems have been intensified by the process of rapid urbanisation. In addition, land subsidence due to over extraction of groundwater in the economic reconstruction period, even further increased the vulnerability of urban areas for flooding. The Tokyo lowland, for instance, is composed of deltaic lowland and reclaimed land. The original elevation of this plain is less than two meters above mean sea level.

Subsidence in Tokyo already started around 1900 because of exploitation of groundwater. During the post-war reconstruction period, groundwater use increased, until control of groundwater was taken in 1961 by introducing strict regulation. In the period to 1965, groundwater use decreased and extraction stopped all together in 1975. By then, some parts already had subsided four meters. This has created about 124 km² of land that is lower than high tide in Tokyo Bay and 32 km² is lower than low tide. Due to the combined effects of geography, climate, urbanisation and land subsidence, the vulnerability of urban lowland areas to flooding is high in Japan. As a result, a wide variety of measures is applied to reduce the vulnerability of urban areas to stormwater induced flooding.

³ This chapter is based on the following publication: De Graaf, R.E., and J. Matsushita (2008). Stormwater management and multi source water supply in Japan: Innovative approaches to reduce vulnerability, pp 143-173. In: De Graaf, R.E. and F.L. Hooimeijer (2008) Urban Water in Japan. Urban Water Series volume 11.

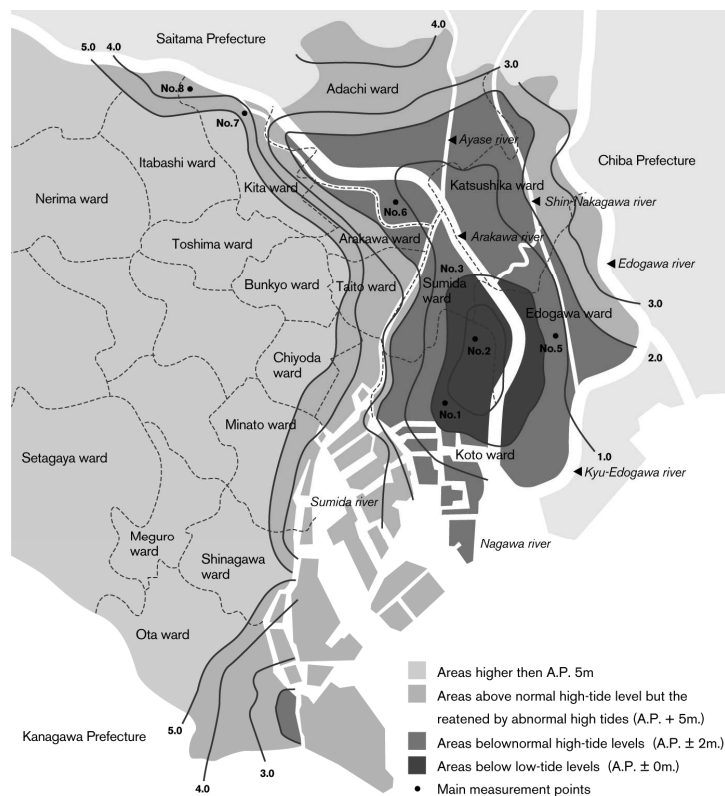
Table 3.1 Design precipitation with a 10 year statistical return period (Araki and Hoes, 2008)

Precipitation	Saga Lowland (mm)	Shiroishi lowland (mm)	The Netherlands (mm)
1 hour	68	61	24
1 day	204	203	52
2 days	269	276	62
3 days	321	332	70

3.2 Four components to reduce vulnerability to flooding

3.2.1 Threshold capacity measures

In order to reduce the vulnerability of urban areas to pluvial flooding, a number of measures have been taken to build threshold capacity. On a national level, during the period of rapid urbanisation, river capacity has been increased multiple times. In addition, artificial floodways such as the Arakawa river in Tokyo were built to process large floods. In the post-war reconstruction period of the 1940's and 1950's, multipurpose dams were built for flood control, water supply and hydro power. Rapid urbanisation limited the possibility for further river enlargements in urban areas (Matsushita, 2007). The government started to make budget available for on-site drainage retention works in 1983. In 1991, The Association for Rainwater Storage and Infiltration Technology was established by the Ministry of Land Infrastructure and Transportation (MLIT). They developed the technical standard for infiltration facilities and published the infiltration guideline in 1995.

**Figure 3.1** The result of land subsidence in Tokyo (Tokyo Metropolitan Government, 1994)

The River Council for river control proposed the necessity of a well-balanced water cycle in urban areas in 1996. Moreover, underground floodways were constructed to bypass floods that result from high intensity rainstorms. An example is the Metropolitan Outer Floodway in Tokyo (Stalenberg and Kikomori, 2008) that was constructed to drain away water from the urban canals and rivers in the Naka and Ayase rivershed. This underground floodway has a discharge pumping capacity of 200 m³/s.

Next to measures on national level, on municipal level centralised sewer infrastructure to prevent stormwater from causing damage was constructed. Similar to many cities in Europe and the United States, Tokyo implemented its first sewer system at the end of the 19th century. Construction of sewers started in 1884 when the brick lined Kanda Sewer was constructed. In the city of Tokyo, still a major part (70%) of the sewer system consists of combined sewer system. The sewer system is gradually upgraded to process a rainfall intensity of 50 mm/hour. For this purpose a 'New Quick Plan for Stormwater' has been issued by the Tokyo Metropolitan Government (2003) that runs from 2004 to 2009. By increasing the sewer capacity, a threshold is built against a large proportion of precipitation events to prevent damage.

A number of decentralised measures are implemented. Examples are source control measures such as local retention, infiltration and storage facilities. Although stormwater infiltration can prevent damage by reducing stormwater flows in the urban environment, it serves multiple purposes such as: groundwater replenishment, prevention of land subsidence, preventing salinity, securing water resources, river flow maintenance and pollution control (Fujita, 1997). Stormwater retention on private area is stimulated by the government with subsidies.

3.2.2 Coping capacity measures

Pluvial flooding can never be completely prevented. Therefore the Japanese have invested in measures that increase their coping capacity. Currently, in order to increase the capacity to cope with flooding, Japan has established comprehensive flood mitigation system that consists of a wide variety of measures. At a national level the following measures are taken to reduce damage (MLIT, 2002):

- Establishment of an evacuation and warning system
- Augmentation of flood fighting capacity
- Publication of maps with historical flood data and flood prone areas
- Encouragement of water robust buildings
- Dissemination among local residents

Communication

In order to successfully implement these measures and involve stakeholders, river basins authorities have been established in heavily urbanised river basins. Dissemination of easy-to-understand flood maps to residents has received increasing attention over the last couple of years. Mass media, cell phones and internet are used to communicate effectively. It is expected that these measures will increase the coping capacity by increasing flood awareness among citizens.

In addition, hazard maps are made of areas that are susceptible to flooding. These hazards maps are publicly available and distributed among residents to improve their response time in case of an emergency. In 1998, Kohriyama City in the Fukushima Prefecture issued an evacuation order because of imminent flooding. Of the people who had seen the map 30% was successfully evacuated against 20% of those who had not seen the hazard map. Moreover, their average

response time was 1 hour faster. (MLIT, 2002) This example gives an indication that communicating hazards maps to residents has positive effects in Japan.

Other examples are measures to increase risk awareness of residents and the operation of a warning system. Historic flood marks are placed along river to make residents aware of the flood risk, for instance in the Ara river near the old sluice gate of Iwabuchi. Another example of a public campaign is the 'Flood prevention month' in June 2001 that was organised by the Tokyo Bureau of Sewerage to demonstrate flood prevention activities and explain the role of the sewerage system (Tokyo Metropolitan Government, 2005).

Legal incentives

To promote private initiatives that reduce flood risks, the central government has established legal incentives such as the cause pay principle for urban development. The most recent incentive is the Countermeasures Act. For large private developments in heavily urbanised river basins, compensating measures have to be taken by the developer, such as ponds, retardation basins or infiltration facilities. This contributes to increased coping capacity of an urban area as well as preventing flooding (threshold capacity).



Figure 3.2 Reducing damage in case of flooding: high level difference between road level and floor level. (Source: Frans van de Ven)

Flood proof urbanisation

Coping capacity during flooding is further enhanced by the construction of elevated infrastructure and flood proof infrastructure. In addition, flood proof urbanisation can contribute to a better recovery after flooding. A number of national highways in Tokyo are elevated to enable transportation of relief goods. Evacuation of residents during disasters is possible as well. Subways are protected against flooding by flood gates and sluices are deliberately over dimensioned and designed to facilitate rapid access of large ships into the city for evacuation and supply of goods during and after a disaster. This contributes to the ability of society to reduce damage.

Moreover, there are houses constructed on stilts or on an elevated level to prevent damage in case of flooding. Figure 3.2 shows a house in the Saga lowland plain in the south of Japan. The large difference between road level and floor level will reduce damage during flooding and allows temporary water storage on roads in the urban environment. Paddy fields are often integrated in the urban environment. In addition to contributing to an improved urban environment and making urban areas less dependent on rural areas, these paddy fields are used as stormwater detention facilities in order to control flooding. Essential access roads are elevated to make evacuation possible during disasters. In every urban district disaster refuge bases have been constructed that enable emergency services to coordinate the disaster procedures. Roads and bridges to refuge bases have been strengthened. Moreover measures have been taken around these bases to make them fireproof and earthquake proof (Matsuda, 1990).

Information systems

Digital warning and information systems are becoming more and more advanced like the Sewerage Mapping and Information System (SEMIS) in 1986, the Tokyo Rainfall Radar System for Tokyo Area (1988) and the AMESH Rainfall Radar system (2006) (Kuno et al., 2008; Matsushita, 2008). These systems enable damage reduction during flooding. The AMESH system provides real time rainfall data that is used for the operation of sewers and wastewater treatment plants. This information is accessible for residents via the website (Kuno et al., 2008).

3.2.3 Recovery capacity measures

Recovery capacity measures include reconstruction of damaged infrastructure and buildings and restoring ecological, social and economic activities in the flooded area. On a national level recovery capacity is developed by the availability of material and equipment to clean up the urban area and reconstruct damaged buildings. Lock gates have been constructed in the Tokyo urban polders that allow rapid shipments of disaster relief goods. To facilitate quick recovery after a disaster, insurance and disaster funds can be effective measures. Both are risk spreading mechanisms in time and space. For a premium, the risk is shared with other residents who experience flood risk. In case of disaster funds the risk is spread over multiple years and over the entire population.

In Japan, there are no disaster funds and residents are responsible for flood insurance themselves. Only a small part of the population takes flood insurance because of the high premiums and relatively low pay out rates of 10 to 20 % (Tatano, 2005). The government agencies do assist in emergency aid and take care of emergency housing. Because key roads are elevated in Tokyo, emergency services are able to enter the disaster area and start with the reconstruction activities and relief for the affected residents. In addition, the provision of

information to residents which areas are safe again, recovery to the condition prior to the disaster is facilitated. The municipality provides this information by maps and internet.

3.2.4 Adaptive capacity measures

Future developments such as climate change, urbanisation and societal demands are uncertain. Reducing uncertainty by predicting climate change and the impacts is done by multiple international organisations such as the Intergovernmental Panel on Climate Change. However, because uncertainty cannot completely be eliminated, adaptive strategies are important.

Chapter 2 described three main components of an adaptive strategy for flood control: building diversity by experimenting with multiple innovations, flexible and reversible infrastructure, and reservation of space by integration of water management and spatial planning. In this research, no examples of flexible and reversible flood control infrastructure were found in Japan. This is still a challenge for future research and development. However, for the other two components, interesting examples were found. These examples will be described in the next paragraphs.

Integration of water management and spatial planning

For integration of water management and spatial planning, spatial measures such as zoning plans are important. Because changes in the spatial structure of a city cannot be easily be reverted, these changes have to allow for flexible choices to be made in the future. Reservations should be made to be able to retain the capacity to adapt to changing physical circumstances in the future, for instance increased rainfall intensity. Land in high risk areas can be reserved for parking, recreation or wildlife. These are functions that allow more flexibility and are less vulnerable to floods than houses or office buildings. In Japan, for this purpose urbanised river basins that are vulnerable to flooding are designated as Urban River Basins under the Urban River Inundation Damage Countermeasure Act (2004) (MLIT, 2006). In an Urban River Basin, permission has to be obtained from the authorities for each development of a certain size that prevents stormwater from infiltrating. Compensating measures have to be taken. An example is the construction of infiltration and storage facilities on the area that is to be developed.

Experimenting with alternative options

At the municipal level, adaptive capacity is strengthened in multiple ways. In Tokyo, the Metropolitan Government decided to start with a wide variety of storage and infiltration facilities in 1982. An example is the ESS (Experimental Sewer System). This system is implemented to build experience with sewer systems that infiltrate and store runoff. From 1983 to 1995 Tokyo Metropolitan Government has built ESS over an area of more than 1,423 ha with 33,294 infiltration pits, 285 km of infiltration trenches and 484,000 m² of permeable pavement. This has proved to be efficient in reducing both the total volume of runoff as well as the maximum runoff intensity (Fujita, 1997). The effectiveness of the ESS is illustrated with an example from Tokyo. In the catchment area of the Shakujii River and the Shirako River there has been a rapid urbanisation process. As a result, the amount of runoff increased and the discharge capacity of the rivers was no longer sufficient. The application of ESS resulted in a 60 percent reduction of the peak discharge (Fujita, 1984).

Another measure that was implemented in the ESS program is the application of permeable pavement. Such surfaces are an alternative to impermeable concrete or asphalt surfaces which would otherwise produce rapid storm water runoff. Permeable pavements enable water to

infiltrate into the ground rather than converting it to runoff. Until 1992, the Tokyo Metropolitan Government has already built about 494,000 m² of permeable pavements which is about 2.3 percent of the total street area (Fujita, 1994).

In addition to implementing technical facilities, the ESS program has provided information and experience on issues such as operation and maintenance, effectiveness, monitoring, and involvement of stakeholders. Knowledge about infiltration systems was further developed, which finally led to the publishing of the Engineering Guideline for Rainwater Infiltration Facilities by Association for Rainwater Storage and Infiltration Technology in 1995. As a result, the application of infiltration facilities became more popular.

3.3 Four components to reduce vulnerability of water supply

The per capita availability of water resources in Japan is comparatively low, about 5200 m³ per capita per year, which is a fifth of the world average (MLIT, 2002). Moreover, the variability of precipitation over the year is large, a third of the potential water resources, or 210 m³ a year is lost as runoff during floods (MLIT, 2002). This may be the reason that in Japan all four components that were mentioned in chapter 2 to reduce vulnerability for droughts are utilised.

3.3.1 Threshold capacity measures

In Japan a large scale centralised water supply has been developed to secure water supply. Reservoirs have been built to cover seasonal changes in precipitation. For this purpose the national government introduced the Multi-Purpose Dam Construction Act in 1957 to meet increasing demand of the economic reconstruction period. These reservoirs are often multi purpose reservoirs that are also used for hydropower and flood control.

In Tokyo, water is mainly supplied from rivers and reservoirs. The total amount of water that is secured by the Waterworks Bureau of the Tokyo Metropolitan Government is 6,23 Mm³ per day, this amount is produced by 11 purification plants and distributed by 34 principal water supply stations and 24,782 km of distribution line. A total amount of 12 million people is supplied with water by the Tokyo water bureau. Water leakage rate has successfully been decreased by maintenance and replacement of infrastructure. The total leakage rate decreased from 10.2 % in 1992 to 5.4% in 2002 (Motoyama, 2004).

At the same time, the Tokyo Metropolitan Government is preventing droughts by demand management. A step tariff system is applied in which the water price increases with higher water use. Demand management is further enhanced by promoting water saving behaviour and appliances. In 1974, it became obligatory for urban development project of 30,000 m² or more (recently upgraded to 10,000 m²), to apply water reduction measures such as rainwater use or water recycling. In 2003, a new guideline was established to achieve the continuous improvement of water efficiency by increasing targets.

The water sources in Tokyo are the Tone, Ara and Tama rivers. Currently, the Tone river is the main source and supplies 78% of the water supply in Tokyo (Motoyama, 2004). The Tokyo metropolitan area relies heavily on these rivers and the water supply capacity of the rivers is almost at its boundary. In the Tama River for example, 80% of the river flow is withdrawn from the river for municipal water supply. Consequently, 75% of the river flow is treated wastewater (Wagner et al., 2002). Also in other rivers in Tokyo, the percentage of effluent in the urban rivers is considerable, with percentages ranging from 17% to even 95.6% (Furumai, 2007).

3.3.2 Coping capacity measures

Rainwater use, stormwater harvesting, greywater recycling and wastewater recycling are technical measures that can assist in reducing impacts of droughts. They also contribute to a better recovery to a normal condition after a drought because multiple sources are used. Basin to basin radar systems have been installed that can assist in coping with droughts. The Japanese national government has actively promoted private initiatives by builder-pay principles. Subsidiary systems to enhance recycling of waste water have been introduced and alternative water use has been mandated for large urban development and urban renewal projects. In addition to the emergency supply system, water use restrictions can be issued by the authority to reduce damage in case of droughts. The River Law amendment of 1997 requires users to take measures in case of droughts or expected droughts. Moreover, river administrators are required to provide information about reservoir levels and enact water reduction measures to residents.

Also at the municipal level measures are taken. To effectively cope with droughts and water supply disruptions during disasters, the waterworks bureau of the Tokyo Metropolitan Government has established an emergency water supply system (figure 3.4). There are 195 emergency water supply bases within 2 kilometres of each resident in Tokyo to improve the city's coping capacity in case of disasters such as droughts. The emergency bases can supply 3 litres of drinking water to 12 million people during 4 weeks. The emergency water tanks constantly reserve fresh water from the main distribution network (Waterworks Bureau, 2005). In addition during dry spells, water transfers within the Tokyo metropolitan area take place to secure service of water supply and reduce the impacts of droughts (figure 3.3).

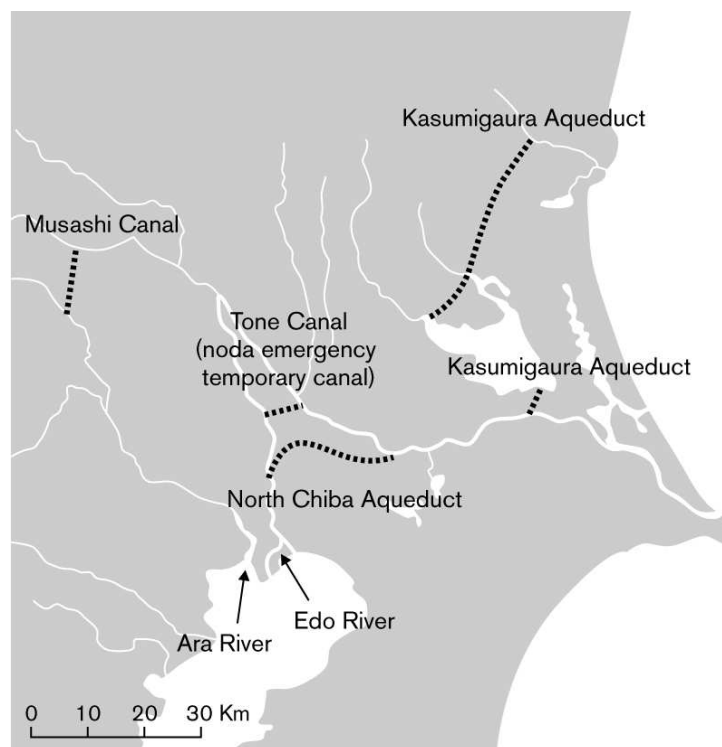


Figure 3.3 River water resources of Tokyo city, dotted lines show the water transfers between rivers that can be used during droughts (MLIT, 2002)

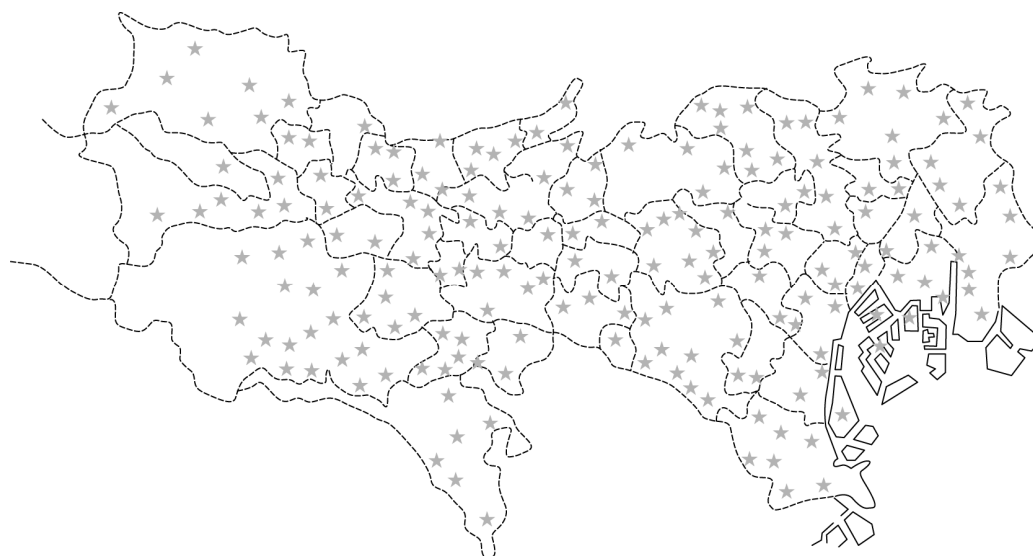


Figure 3.4 Location of emergency water supply bases in the city of Tokyo, on the right side of the map, Tokyo Bay (Waterworks Bureau Tokyo, 2005)

3.3.3 Recovery capacity measures

During and after droughts, certain sectors have priority over others for water resources on a national level. Inter-sector water use converting is used to recover from droughts and to establish a functioning water system again. Drinking water supply has the highest priority of the water use functions.

In Tokyo, the Waterworks bureau has established an Emergency Water Services Squad to handle unexpected accidents and emergencies in order to recover quickly. The squad consists of 6 water tank trucks, 1 anti disaster vehicle, 3 emergency publicity cars and 4 investigations cars. This squad is available around the clock to be able to rapidly establish a functioning water system again after an emergency. Moreover the squads organise emergency preparedness trainings with other government agencies every year (Waterworks Bureau Tokyo, 2005).

Multi source water supply is another measure that is used to recover from droughts and other emergencies. Tokyo does not rely on only one source, a variety of water sources is used: river water, stormwater, grey water, reclaimed wastewater. As a result the recovery to a sufficient water supply system goes more quickly if one of these sources is affected. Some municipalities have implemented in-house water recycling systems and rainwater utilisation systems. A good example is the Tokyo Dome. In the Tokyo Dome water retention capacity has been installed to enable utilisation of rainwater for low quality purposes such as toilet flushing. Stormwater from the roof (16,000 m²) is stored in retention storage of 3000 m³ under the stands. Of the total amount of storage, one third is reserved for fire fighting, one third is reserved for toilet flushing and one third is kept empty to use for stormwater retention during heavy rainfall. In normal years hardly any water is used from the main water pressurised water system for toilet flushing. As a result water use is much lower and the building is less vulnerable to droughts. The ability to bounce back after a drought is higher because it has multiple water sources at its disposal. It also reduces damage in case of drought (coping capacity) and contributes to the number of options society has available to adapt to uncertainties (adaptive capacity).

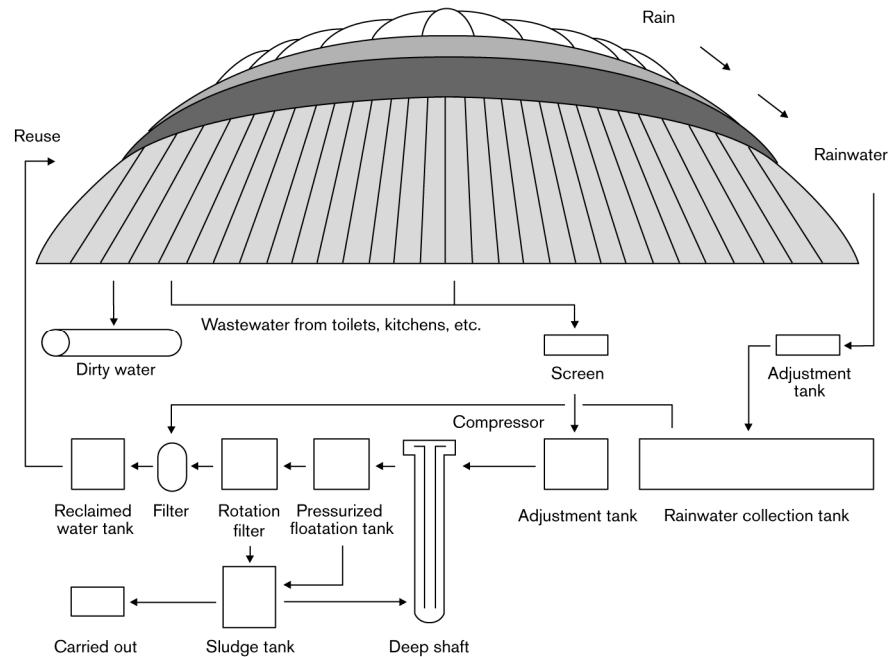


Figure 3.5 Treatment scheme of runoff and recycled water in Tokyo Dome (De Graaf and Matsushita, 2008)

3.3.4 Adaptive capacity measures

Anticipating on uncertainties of future water demand and supply can be done by studies on climate change impacts on water resources and water use projections. However, this is unlikely to provide absolute certainty. In chapter 2, two strategies were mentioned that contribute to improving adaptive capacity of water supply: experimenting with other modes of water supply to build diversity, and flexible and reversible water supply infrastructure. This paragraph describes Japanese examples of both components.

A flexible water supply

At a municipal level, adaptive capacity to secure water supply can be improved by considering the full range of urban water sources and their possible functions. Examples of urban water sources are river water, groundwater, desalinated sea water, stormwater, grey water and recycled water. By utilisation of the full range of urban water resources in a flexible way, according to the local circumstances, the city is better able to adapt to its physical surroundings.

Treated wastewater in Tokyo is used for many urban purposes; there are 560 locations in which recycled water is used. These locations are private buildings, public buildings and large scale recycle schemes (Furumai, 2007). Already in 1979, subsidiary schemes were introduced to promote the use of recycled wastewater system (Matsushita, 2007). Instead of a waste, reclaimed wastewater can be considered as a valuable resource with commercial value that is locally available and is a constant supply. A proportion of 8.8% of the wastewater is recycled for a variety of purposes (Fujita, 2007). Examples of functions are: road cleaning, sewer cleaning, pavement cooling, train cleaning, urban stream restoration, heating and cooling of buildings, low quality residential purposes, park irrigation, fire fighting, and snow melting on public roads. The Ariake wastewater treatment plant in Tokyo supplies treated effluent to a nearby apartment complex for toilet flushing. The wastewater treatment plant supplies the water at a competing rate (260 Yen/m³) compared to normal drinking water supply (450 Yen/m³) (Van de Ven, 2006b).

In the Shiodome, Tokyo, experiments are executed to use effluent to cool roads in order to contribute to reduce the urban heat island effect.

Another innovative approach is the use of effluent for heating and cooling of buildings such as hospitals and hotels. One of the buildings where this concept is applied is the Tokyo Dome Hotel. Figure 3.6 shows that recycled wastewater is also used for landscaping, irrigation and urban stream restoration. The Kitazawa (Fujita and Geldof, 2008) is an example of a severely degraded urban stream in Tokyo that uses recycled water for regeneration of the river. The presented examples show that by using multiple urban water sources for a variety of purposes, experience with new modes of water supply is built and the dependence of external river water resources decreases. Changes in one or more sources due to climate change can be better accommodated in a flexible multisource water system compared to cities that depend on one source that might be disrupted in the future. Therefore, multisource water supply can be considered an adaptive strategy.



Figure 3.6 Multiple uses of recycled water in the urban environment, from the top left clockwise: road cleaning, sewer cleaning, cooling of pavement, park irrigation and urban stream restoration (Source: Fujita, 2007)

Build diversity

By innovative forms of urban design, recharge of runoff to the groundwater is promoted and urbanisation is prevented in areas that are important as water catchments. In addition, subsidies, corporate or income tax benefits and low interest loans are available for projects that utilise alternative water resources. There are approximately 2,800 large scale systems of water recycling or rainwater use in Japan.

Society has predominantly experience with utilizing treated river water for all residential and industrial purposes, demonstration projects with other modes of water supply are necessary to build experience and reduce uncertainties. In Tokyo there are many demonstration projects with other modes of water supply and the use of the full range of urban water resources for all kinds of urban purposes. Stormwater is used in Tokyo for functions such as toilet flushing and fire fighting. Residents are encouraged to install stormwater storage on their private property. The subsidy system was established in 1995. Figure 3.7 shows a stormwater utilisation scheme in a Japanese house. Stormwater is used for garden irrigation, carwash and laundry first and afterwards reused for toilet flushing.

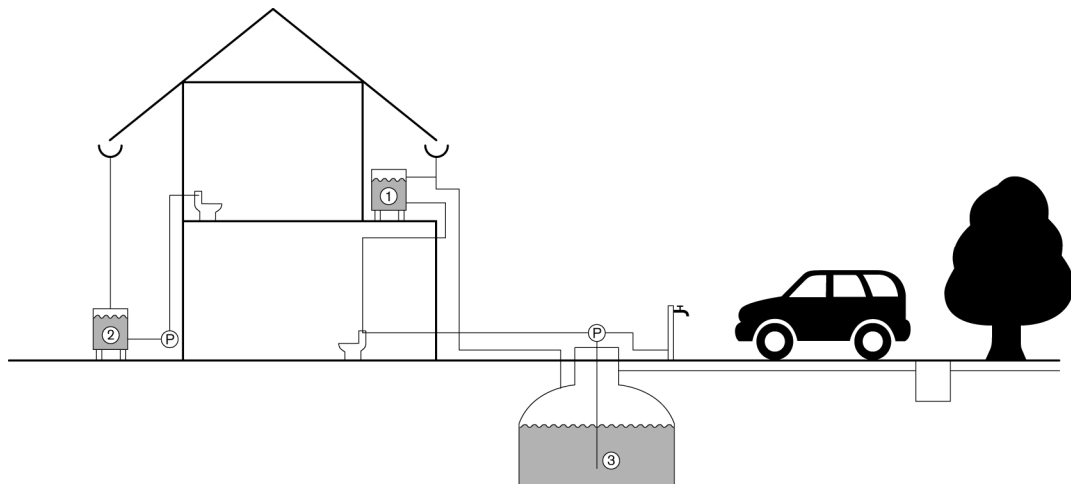


Figure 3.7 Three types of stormwater utilisation scheme in a Japanese house (1) Indoor, (2) Outdoor and (3) Underground (Fujita, 2007)

3.4 Comparison between Japan and the Netherlands

Both Japan and the Netherlands have a developed urban water infrastructure. Threshold capacity to prevent disasters is well developed in both countries. However, the four component vulnerability framework analysis indicates some remarkable differences between urban water management in Japan and the Netherlands. For pluvial flooding an example is the large level difference between floor level and road level that reduces damage during flooding. For water supply an example is the use of recycled water and the availability of an emergency water supply in Tokyo. This reduces vulnerability because a city no longer depends on one resource but uses a whole range of water resources, both local and external resources. In the Netherlands the focus is more on preventing disasters by increasing threshold capacity while the other three components are neglected.

Adaptive capacity is partly developed in Japan. On one hand technology development and demonstration projects for water supply, water robust urbanisation and stormwater management are applied at a local scale. The experimental sewer systems (ESS) and the use of recycled wastewater for a variety of purposes are good examples. On the other hand, also Japan still has to develop more flexible and reversible infrastructures that allow for future adaptations to be made. Also in Japan the current centralised urban water management infrastructure has a long expected lifespan and a low adaptability. However, the diversity of well-developed technical options that have been described in this chapter provides the Japanese society with a wide range of options to anticipate on uncertain future developments. The adaptive capacity is different from in the Netherlands for two reasons. First, the adaptive capacity in Japan is not the result of an explicit adaptation government policy. Japan is highly exposed to natural hazards and the country had to react on huge urbanisation and land subsidence. Increasing threshold capacity only, was no longer sufficient to protect the urbanised delta. Therefore, other measures became important, leading to a high diversity of technical infrastructure and thus to a higher adaptive capacity. In addition there is a political willingness to experiment and to try different options, as the ESS example demonstrates. In the Netherlands, on the contrary, disasters happen rarely. The last major flood occurred in 1953 and the last severe drought in 1976. In addition, the Dutch tradition to protect the country by increasing threshold capacity is still very strong.

Second, in the Netherlands, spatial reservations for future water storage capacity seem better developed. In Japan, spatial reservations for water storage are problematic because the strong status of land ownership. Moreover, space in cities and along rivers is even scarcer than in the Netherlands. Because spatial development is much more private sector driven compared to the government planning culture in the Netherlands, incentives have been made to promote stormwater infiltration and water recycling among private actors. Examples are cause-pay-principles, design manuals, subsidy schemes, binding targets and public awareness campaigns. Involvement of the private sector and the creation of a market by binding legislation have resulted in a large and growing eco-industry.

Currently, it is recognised by the Dutch government that a more adaptive strategy should be applied in water management to anticipate on climate change (e.g. Van der Brugge et al., 2005). However, this has not yet materialised in adaptive technical infrastructure. Japan's urban water systems, illustrate the possibility to incorporate all four components of the framework to reduce vulnerability of urban areas. Diversity, private sector and citizen involvement and initiatives at a local scale to supplement large scale centralised infrastructures are crucial. Japan on the other hand, could learn from the Dutch approach to develop climate change adaptation and spatial planning policies for the long term and on a high spatial scale.

3.5 Conclusion

The purpose of this chapter was to illustrate the vulnerability framework, and to explore and generate ideas for alternative water management options using Japan as an example. Japan is a country that is frequently exposed to various natural hazards including flooding and droughts. Many local scale urban water management technologies were described in this chapter that contribute to coping and recovery capacity. In Japan, the availability of a wide range of technical options also increases the adaptive capacity. Based on the vulnerability analysis in this chapter it can be concluded that in Japan all four capacities of the framework are used to reduce vulnerability of urban lowland areas. For urban pluvial flood control, not only improving sewer capacity is applied but also risk communication, stakeholder involvement, emergency plans, wet proofing of buildings and elevated houses and infrastructure. Other coping and recovery capacity improvement measures that reduce the effects of flooding are stormwater infiltration and retention and securing access to flooded areas by elevated roads and emergency ship locks.

With regard to water supply, Tokyo does not only focus on better and more efficient water storage and delivery infrastructure but also on demand management, water recycling, water saving technology and decentralised, more flexible water supply. A range of urban water resources is used, including stormwater and recycled wastewater. In particular recycled waste water is used for a whole range of urban functions, reducing drinking water demand and decreasing the dependence of the city on external river water resources. In addition, emergency water supply system has been installed to be able to cope with droughts and other disasters that may disturb the water supply system. To better adapt to future water shortages, demonstration projects with new modes of water supply are executed. New technical options are developed for the future. Examples are the Experimental Sewer Systems (ESS) and demonstration projects with multiple urban water sources such as stormwater, recycled water and wastewater effluent. This strategy provides diversity to the options society has available to face uncertain future developments and disturbances. This chapter provided a broad overview of possible options to reduce vulnerability by innovations in urban water management. In the next chapters, the feasibility of two specific urban water management innovations is studied in Dutch case studies.

4 Case study Heerhugowaard, use of local water resources

4.1 Introduction

Chapter 2 identified the use of local urban water resources as a strategy to reduce the vulnerability of water supply. By using a ‘portfolio’ of multiple water resources, including local resources and external resources, urban areas become less dependent on one source of water that might be disrupted in the future. Local water resources contribute to coping capacity, recovery capacity and adaptive capacity. The previous chapter also provided examples of Japan where local rainwater, stormwater and recycled water are used for various purposes on a large scale. Also in other countries alternative water sources are applied (KIWA, 2004). Good examples are Australia (Mitchell, 2006) and Belgium (VMM, 1999). In Belgium, the construction of a rainwater tank is obligatory for new houses and redevelopment of houses with a roof area larger than 75 m².

In the Netherlands, the use of rainwater for residential purposes is hardly applied. A possible explanation is the restrictive government policy after a wrong connection in a third pipe system in the Leidsche Rijn development area near Utrecht (Van Geel, 2003). There are also concerns about public health risks (RIVM, 2005). Rainwater is contaminated with micro-organisms that may impose a public health risk. According to recent research it is plausible that people swallow 4µl of flushing water a year by inhalation of aerosols during toilet flushing (RIVM, 2007). Consequently the infection risk could theoretically exceed the standard of 1 per 10,000 persons in the public health drinking water regulation. However, toilet flushing with clean drinking water possibly also distributes aerosols with faecal contamination. After all, in toilets there is direct contact between water and faecal matter. It is not known if this risk might be higher than the distribution of aerosols from rainwater. Any human activity imposes certain public health risks. In case new practices are rejected based on public health risk, there should be a comprehensive comparison with public health risks of current practice and risks of other social activities.

Another reason why rainwater harvesting is hardly applied in the Netherlands is the perceived abundance of water. However, as chapter 2 demonstrated, this is largely because of the continuous inflow of transboundary rivers, in particular the Rhine. Due to climate change, the flow regime may change and more droughts are expected in the future. In addition, new government policy on water management (Tielrooij, 2000) highlights the importance of local water retention and storage and reducing combined sewer overflows (CSO’s) by disconnecting rainwater from the sewer system. Rainwater harvesting potentially contributes to these objectives.

In this chapter the feasibility of using the local water system in a new urban development in the Netherlands, ‘*De Draai*’ in Heerhugowaard, is studied. The study included the following research questions.

- 1) What is the feasibility to use local urban surface water for the decentralised production of drinking water?
- 2) What are the water quantity and water quality risks of decentralised water supply
- 3) To what extent can local rainwater be used to reduce drinking water demand?

In addition to the technical research questions, another objective of this research was to develop insight in factors that determine whether or not innovations are eventually applied in practice. For this purpose, the author of this thesis actively participated in the case study as a reflective practitioner. The results are described in the section ‘translation to practice’.

4.1.1 Case study background

In the municipality of Heerhugowaard in the northern part of The Netherlands is a medium size municipality with 50,000 citizens. In this municipality a new urban district of about 2800 houses, De Draai, will be developed. The ambition of the municipality Heerhugowaard is to give the urban water system more economic value. Consequently, the urban water system is used as a source for sustainable energy (see chapter 5) and for floating urbanisation (chapter 6). Moreover, the municipality aims to become the first municipality in the Netherlands that achieves a CO₂ neutral emission status. De Draai should be an example of a sustainable adaptive urban environment. The urban development plan is based on the preferences of future residents. A demand driven urban planning optimisation module of the ETH Zürich (Karres and Brands, 2006) is applied for this purpose. For water management the objective of the municipality is to achieve a self-supporting water system, with minimal supply of water resources from surrounding areas. For this purpose, a high proportion (12%) of the total development area will be constructed as surface water. The average terrain level is -2.5 meter below mean sea level. Table 4.1 presents terrain data of the development area.

Table 4.1 Terrain data of the development area (Karres and Brands, 2006)

Terrain data		Area (ha)	%
Paved area		49.6	34
	Roofs	17.1	12
	Asphalt roads	7.1	5
	Paved roads, parking places	25.4	17
Unpaved area		78.6	54
	Surface Water	16.8	12
Total		145	100

4.1.2 Project team approach

The project⁴ was started as a 'Bridging Project' between two research programs: Leven met Water and Delft Cluster. In the project plan of the Transition SUW project (2005) the use of local water resources was mentioned as one of the innovative concepts to be studied in the project. The first project plan for this specific case study was written in August 2007. The project was executed as a joint case study of the Transitions SUW project and the research project Flexwater of KWR Water Cycle Institute. Flexwater is part of the BTO Joint Research of the Dutch drinking water sector. Flexwater focuses on multi-source strategy of water supply and increasing the flexibility of water resources management and treatment (Meuleman et al., 2007). The following project partners cooperated in the study: TU Delft, KWR, Municipality of Heerhugowaard, Drinking water company PWN and the Waterboard Hollands Noorderkwartier. The research was executed

⁴ For more information about this project the reader is referred to the final report. Van den Berg, G., S. de Rijk, G. Mesman, A. Abrahamse en R.E. de Graaf (2008). Kansen voor decentrale drinkwatervoorziening in Nederland. Flexwater pilot De Draai, Heerhugowaard. BTO(s) 2008.018, Leven met Water rapport P1002.2008.2

by the author of this thesis (TU Delft) and KWR from November 2007 to June 2008. The other project partners formed a joint steering group.

The project was a good example of an integrative approach that was described in chapter 1. Scientific relevant research questions were investigated based on a real case study in practice. Practitioners participated in the project to develop insights on the feasibility of using local water resources. Another reason for them to participate was that society increasingly demands sustainable solutions from water institutions. The project was based on collaboration between researchers and practitioners. The research plan was written by the researchers, with assistance from practitioners in a couple of meetings.

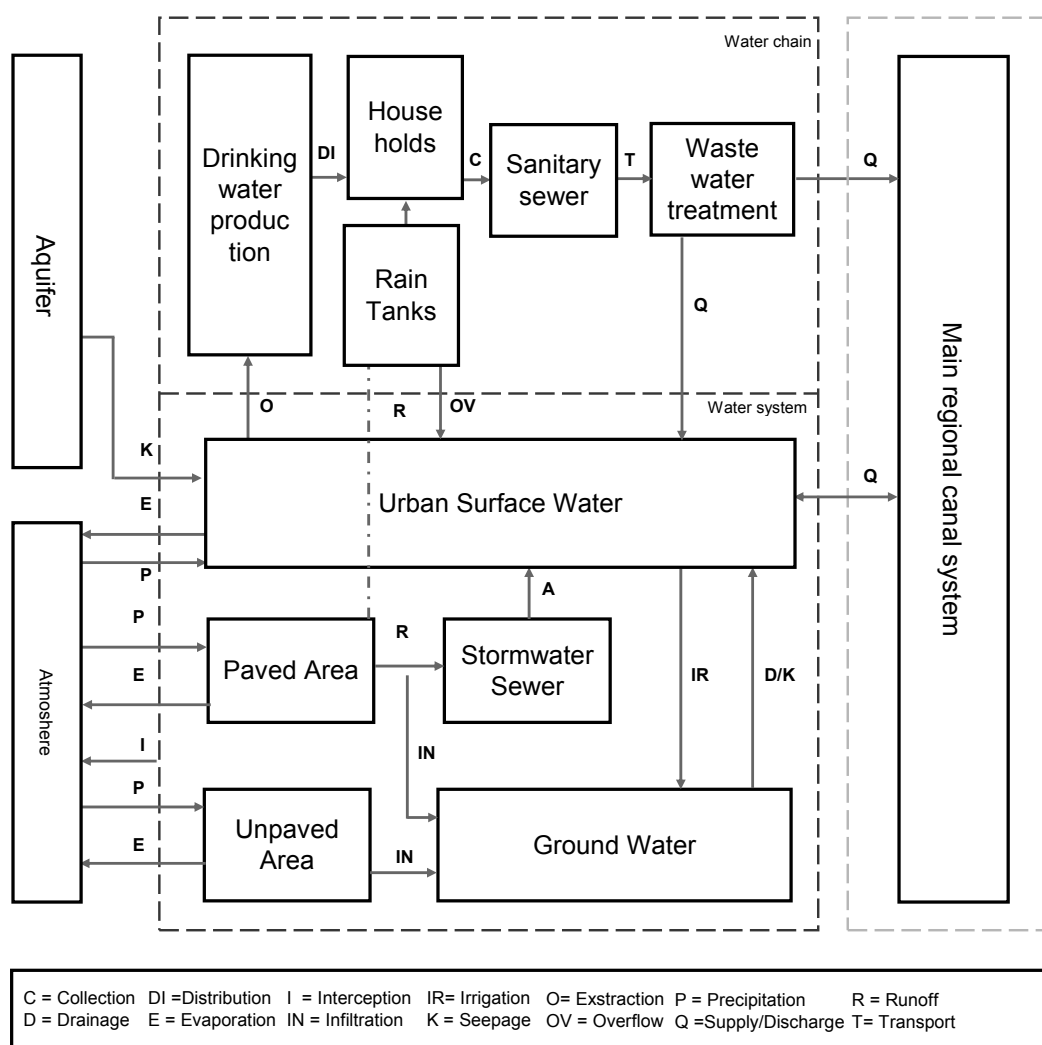


Figure 4.1 Schematisation of water system of De Draai

4.2 Methodology

Four scenarios of water demand were applied in this study.

- 1) Conventional centralised water supply, current water demand (base case)
- 2) Decentralised water supply, local water purification, current water demand
- 3) Decentralised water supply, local water purification,
 - a. Reduced demand by rainwater harvesting for all houses, including apartments
 - b. Reduced demand by rainwater harvesting for all one family houses

Scenario 1 and 2 were compared to evaluate the feasibility of using the local urban water system as a source for local drinking water production. This means drinking water was produced from the local urban surface water system instead of connecting the urban district to the regional network. Figure 4.1 presents the schematisation that was used for the calculations in the spreadsheet model in this study. The main differences compared to figure 1.1 are the raintanks that are installed and the installation of local drinking water production. Scenario's 3a and 3b were used to study the additional effect of local rainwater harvesting. For calculation of rainwater harvesting and overflow of raintanks in these scenarios, the KWR rainwater module (Van den Berg et al. 2008) was used.

The project aimed to investigate both the feasibility under average circumstances and extreme conditions. From the time series three situations were specifically studied:

- 1) Average year (based on time series 1906-2003)
- 2) Extremely dry year 1921, estimated return period $T=40$ years (Beersma en Buishand, 2002)
- 3) Dry year 2003, estimated return period $T=10$ years (Riza, 2005)

In the spreadsheet model, a time step of 1 day was applied following the data availability of evaporation and precipitation (daily records). Since the objective of this study was to investigate the local water availability during long periods (seasonal timescale), a sensitivity analysis to investigate the effect of the time step on water levels during extremes was not considered useful in this phase of the project. There were two connected reservoirs, the urban surface water and the urban groundwater. These were computed as follows.

$$h(t+1) = h(t) + \frac{Q_p + Q_r + Q_d + Q_s + Q_{rw} + Q_{ov} - Q_{ps} - Q_e - Q_{wp}}{A_s} \cdot \Delta t \quad (4.1)$$

With:

h	= Surface water level compared to target (m)
Δt	= Timestep (1 day)
Q_p	= Direct precipitation on surface water (m ³ /d)
Q_r	= Runoff discharge (m ³ /d)
Q_d	= Drainage to surface water system (m ³ /d)
Q_s	= Groundwater seepage (m ³ /d)
Q_{rw}	= Supply from regional water system (m ³ /d)
Q_{ov}	= Overflow from rain tanks (m ³ /d)
Q_{ps}	= Drainage to regional water system (m ³ /d)
Q_e	= Evaporation from surface water (m ³ /d)
Q_{wp}	= Extraction for drinking water production (m ³ /d)
A_s	= Area surface water system (m ²)

$$h_{gw}(t+1) = h_{gw}(t) + \frac{Q_i - Q_d}{A_t \cdot p} \cdot \Delta t \quad (4.2)$$

With:

H_{gw}	= Groundwater level compared to target (m)
Q_i	= Infiltration(m ³ /d)
Q_d	= Drainage to surface water system(m ³ /d)
A_t	= Area terrain (m ²)
p	= Porosity (-)

Precipitation

Daily rainfall data (1906-2003) from station De Bilt were used (KNMI, 2006). The distance of this station to Heerhugowaard is 67 km. Measurements from stations that are nearer to Heerhugowaard were also available. However, they were available only for much shorter time series. Water systems will be in place for decades after they are installed. Therefore, data from De Bilt were used to evaluate the reliability of alternative water supply over a long period.

Evaporation

Daily evaporation measurements (1906-2003) from station De Bilt (KNMI, 2006) were used for reference evaporation E_r . For open water evaporation a factor of 1.2 was applied. This factor was based on comparison of the reference evaporation E_r with the Penman open water evaporation E_o under Dutch circumstances (De Graaf, 2005). For evaporation from parks and gardens a seasonal factor of 0.85 (Van de Ven, 2006a) was applied during the three summer months. Evaporation from paved areas was assumed to be equal to interception.

Interception

Wetting losses by interception in the model were based on Pecher (1969). The following values were applied.

Roofs	0.3 mm
Asphalt	0.2 mm
Paved area	0.35 mm
Unpaved surface	0.3 mm

Infiltration

Infiltration on green areas was assumed to be 100% of net rainfall, taking into account interception losses. Infiltration on paved areas was computed based on Van de Ven and Voortman (1985). The net infiltration coefficient was 0.47.

Runoff

Runoff from paved areas was based on a rational method with taking into account initial losses by interception. Runoff coefficients were used following Van de Ven and Voortman (1985). For roofs and asphalt roads the runoff coefficient is 1. For paved areas, the runoff coefficient is 0.53. The net runoff after interception was computed as follows.

$$Q_r = C_t(i - l_i)A_t \quad (4.3)$$

With

C_t	= Runoff coefficient based on terrain type (-)
i	= Daily rainfall intensity (m/d)
l_i	= Interception (m/d)
A_t	= Total paved area area (m ²)

Drainage

Drainage from groundwater to surface water is computed in the spreadsheet model based on Darcy's law.

$$Q_d = -k_t \cdot i \cdot A \quad (4.4)$$

$$i = \frac{h - h_{gw}}{0.5D} \quad (4.5)$$

$$A = \frac{A_d \cdot (d_{eq} - f + h)}{0.5D} \quad (4.6)$$

k_t	= Permeability (m/d)
i	= Slope of energy line (-)
A	= Drainage cross section (m ²)
D	= Drain distance
A_d	= Development area (m ²)
d_{eq}	= Hooghoudt equivalent depth (m)
f	= Freeboard (m)

Groundwater seepage

Groundwater seepage was assumed at a constant rate of 0.1 mm/d based on a previous study (Nelen and Schuurmans, 2006).

Supply from the regional water system/ pumping station

Pumping station capacity was based on the design standards of the watersystem of De Draai (Nelen and Schuurmans, 2006). The following values were applied.

Allowable water level rise	0.3 meter + target level
Pumping station switch on	0.15 m + target level
Capacity pumping station	0.12 m ³ /s, or 6.9 mm/day
Supply capacity sluice	0.095 m ³ /s, or 5.7 mm/day

Extraction for drinking water production

The following water use figures were obtained from the regional water utility PWN and applied in the spreadsheet model. No water use factors were applied for higher water use in dry years.

Projected number of citizens	6420
Water use	118 lpppd
Total water use	758 m ³ /d

Table 4.2 Data and assumptions that are used in the calculation

System component	Value	Source
Number of houses	2816	(Heerhugowaard, 2002)
Average roof area house	50 m ²	(Karres en Brands, 2006)
Number of people per house	2.28 capita per house	(CBS, 2005)
Number of single family houses	1126	(Karres en Brands, 2006)
Roof area single family house	66 m ²	(Karres en Brands, 2006)
Number of people per house	4	
Volume rainwater tank	3 m ³	
Groundwater system		
Drainage depth	0.7 m	(Nelen and Schuurmans, 2006)
Seepage	0.1 mm/day	(Nelen and Schuurmans, 2006)
Distance subsurface drains	30 m	(Nelen and Schuurmans, 2006)
Permeability K	2 m/d	(TNO, 2006a)
Hooghoudt equivalent depth	2.33 m	
Storage coefficient	0.25	

4.3 Feasibility local water production

4.3.1 Water quantity

Scenarios 1 and 2 were studied with the spreadsheet model to evaluate the water quantity feasibility of using the local urban surface water system as source for drinking water production. Table 4.3 presents the results. In an average year there is no supply of water from surrounding areas required for a conventional system (scenario 1). If the local urban water system is used as a source for decentralised drinking water production, only a small amount of water (0.6%) is required on a yearly basis to achieve a closed water balance. The total extraction for drinking water supply by the citizens of De Draai amounts to 191 mm on a yearly basis, or 23% of the annual water balance. The required pumping volume to the regional water system decreases with 46% between scenario 1 and 2 in an average year if local water resources are used for drinking water production.

Table 4.3 Yearly Water balance De Draai under different scenarios

	IN (mm)	%		OUT (mm)	%
AVERAGE YEAR					
Scenario 1: Conventional centralised water supply					
Precipitation	789.7	95.6	Evaporation	414.2	50.1
External supply	0	0	Pumping station	411.8	49.8
Seepage total	36.5	4.4	dS (storage)	0.2	0
Total	826.2	100	Total	826.2	100
Scenario 2: Decentralised water supply, local water purification					
Precipitation	789.7	95	Evaporation	414.2	49.8
External supply	5.3	0.6	Pumping station	226.7	27.3
Seepage total	36.5	4.4	Extraction	190.7	22.9
dS (storage)	0.2	0			
Total	831.7	100	Total	831.7	100
EXTREMELY DRY YEAR (1921)					
Scenario 1: Conventional centralised water supply					
Precipitation	387.3	71.0	Evaporation	448.4	82.3
External supply	0	0	Pumping station	96.8	17.7
Seepage total	36.5	6.7			
dS (storage)	121.4	22.3			
Total	545.2	100	Total	545.2	100
Scenario 2: Decentralised water supply, local water purification					
Precipitation	387.3	57.5	Evaporation	448.4	66.6
External supply	113.2	16.8	Pumping station	34.6	5.1
Seepage total	36.5	5.4	Extraction	190.7	28.3
dS (storage)	136.1	20.3			
Total	673.7	100	Total	673.7	100
DRY YEAR (2003)					
Scenario 1: Conventional centralised water supply					
Precipitation	612.7	92.5	Evaporation	462.1	69.7
External supply	0	0	Pumping station	200.5	30.3
Seepage total	36.5	5.5			
dS (storage)	13.4	2.0			
Total	662.6	100	Total	662.6	100
Scenario 2: Decentralised water supply, local water purification					
Precipitation	612.7	82.5	Evaporation	462.1	62.2
External supply	34.0	4.6	Pumping station	89.9	12.1
Seepage total	36.5	4.9	Extraction	190.7	25.7
dS (storage)	59.5	8.0			
Total	742.7	100	Total	742.7	100

Results show that in an extremely dry year a self-supporting water supply is not feasible. The shortage amounts to 16.8% on an annual base. In scenario 2, not enough water resources are available to produce all drinking water from the local urban water system. External supply is required to fulfil the water demand. In addition, a significant part of the local groundwater and surface water resources are used. The proportion of water that is pumped away from the area decreases significantly compared to an average year. However, the results show that new urban developments can be much more self-supporting than is the case today. Even in a dry year (2003), the required external supply is less than 5%, due to the high storage capacity of De Draai watersystem. Another question is whether local water resources should cover all residential water demand. Local resources could also be used to cover household purposes that require low water quality, such as toilet flushing, garden irrigation and clothes washing.

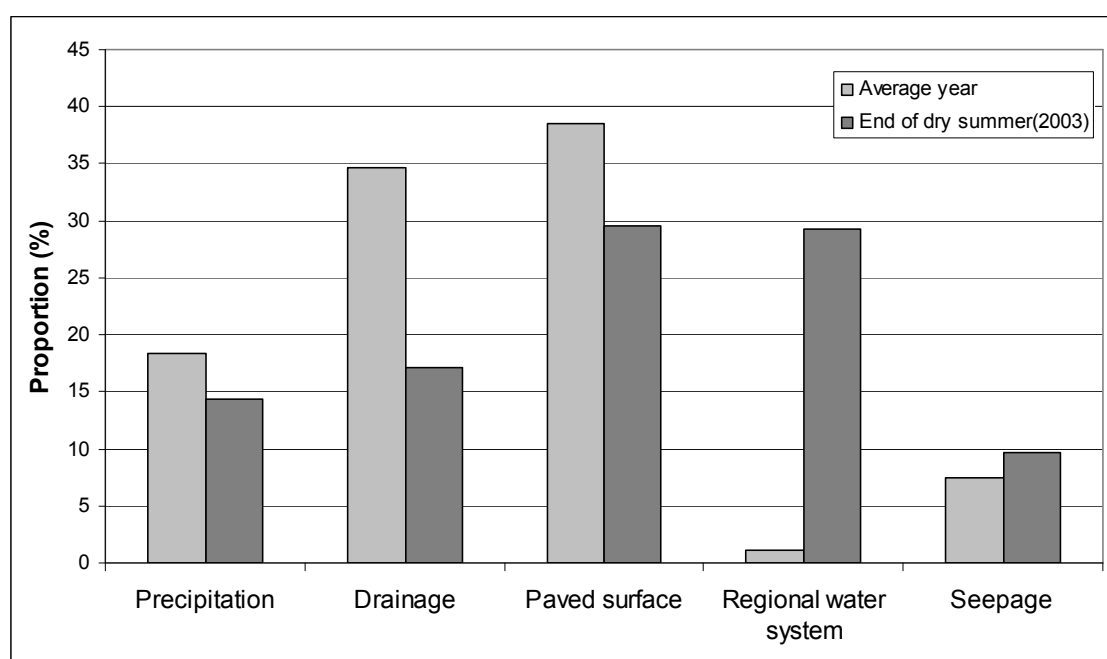


Figure 4.2 Sources of surface water in De Draai in an average year and at the end of dry summer in scenario 2: decentralised water supply

4.3.2 Water quality and proposed treatment scheme

The surface water in Heerhugowaard originates from the sources that were described in figure 4.1. In a critical situation, for instance the end of the summer of a dry year (2003), a large proportion of the urban surface water originates from the regional water system. This water often has a poor quality. By analyzing the cumulative flows in the year 2003, a figure that presents the proportion of water sources was produced from the spreadsheet model. The sources of the urban surface water in De Draai are presented in figure 4.2.

Table 4.4 Rainwater quality (RIVM, 2008)

	pH	K25 µS/cm	Cu µg/l	Co µg/l	Pb µg/l	Ni µg/l	Zn µg/l	Fe µg/l	Mn µg/l
Average	5.4	37	2.2	0.05	2.6	0.43	9.2	60	3.6
Median	5.2	32	1.5	0.04	2.3	0.38	7.3	44	3.3
90percentile	6.3	60	4.7	0.09	4.5	0.66	18.6	115	5.9
N	128	132	153	67	153	79	153	152	12
	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Cl mg/l	PO₄ µg/l	SO₄ Mg/l	NO₃ mg/l	NH₄ mg/l
Average	0.46	0.35	0.25	2.8	4.9	31.7	3.1	2.5	1.3
Median	0.38	0.28	0.20	2.1	3.8	3.8	2.6	2.1	1.1
90percentile	0.72	0.63	0.42	5.3	9.4	75.5	4.9	4.0	2.1
N	133	133	132	133	133	132	133	133	132

Table 4.5 Subsurface drainage water quality (RIVM, 2002)

	NO3 mg/l	NH4 mg/l	N-org mg/l	N-tot mg/l	OrthoP mg/l	P_{tot} mg/l	Cl mg/l	SO₄ mg/l	Zn µg/l
Average	27	1.59	1.2	8.9	1.1	1.1	284	111	<13
Min	<0.1	0.09	0.29	7.3	0.02	0.03	18	58	<13
Median	29	0.38	0.83	8.9	0,18	0.28	133	86	<13
Max	43	7.9	2.2	10	4.4	4.5	1560	227	32.7

Table 4.6 Quality of stormwater runoff (STOWA, 2007)

	Cd µg/l	Cr µg/l	Cu µg/l	Hg µg/l	Pb µg/l	Ni µg/l	Zn µg/l	PAH10 µg/l	PAH16 µg/l
Average	0.26	6.0	26	0.05	33	5.4	194	0.8	1.0
Median	0.15	1.1	10	0.06	12	3.5	95	0.3	1.1
90percentile	0.49	11.0	47	0.08	75	10.0	450	1.2	1.3
MAR	2.0	84	3,8	1.2	220	6.3	40	4.3	4.3
N	151	140	168	118	164	153	163	51	23
	Min oil mg/l	Cl mg/l	Fe mg/l	BOD mg/l	COD mg/l	Ptot mg/l	N-Kj mg/l	SS mg/l	E-coli cfu/100 ml
Average	0.7	27	1.0	6.7	61	0.42	2.3	43	3.0*10 ⁴
Median	1	6.0	1.1	4.0	32,0	0.26	1.7	30	1.2*10 ⁴
90percentile		60	2,9	14.0	110	0.97	6.2	140	1.2*10 ⁶
MAR						0.15	2.2		1.0*10 ³
N	149	92	60	69	78	107	100	76	76

Table 4.7 Waterquality regional watersystem measurements Kanaal Rustenburg-Opmeer (2001-2007) (source: Hoogheemraadschap Hollands Noorderkwartier, 2008)

Parameter	Unit	Measurements (2002-2007)	n	Standard drinking water law for water intake
Temperature	°C	4 – 21	12	25
pH	-	7.4 – 8.7	12	7.0 < pH < 9,5
Oxygen	mg O ₂ /L	6 – 19	12	> 2
Conductivity	mS/m	78 – 134	12	125 at 20°C
Susp. Particles	-	-	0	-
Chlorofyl-a	µg/L	9 – 225	5	-
DOC	mg/l	-	0	-
Chloride	mg/l	87 – 175	12	150
Na	mg/l	55-90	6	150
Ca	mg/l	65 - 210	9	-
Mg	mg/l	18 – 24	6	-
Ba	-	-	0	-
Si	-	-	0	-
Sulphate	mg/l	100 - 240	9	150
Nitrate + nitrite	mgN/L	< 0.2 – 1.86	8	50
Ammonium	mgN/L	0.03 – 0.83	12	0.20
Total org N	mgN/L	1.06 – 2.61	5	-
Total anorg N	mgN/L	< 0.27 – 2.4	8	-
Ortho-P	mgP/L	0.08 – 0.45	12	-
Total-P	mgP/L	0.15 – 0.46	9	-
BOD	mgO ₂ /L	<3 – 11	8	-
MCPA	µg/l	0.28	1	0.1
MCP	µg/l	0.06	1	0.1

A water quality analysis was executed. Water quality of rainfall was based on the national precipitation measurement network (RIVM, 2008). Drainage water quality was based on drainwater quality measurements of 37 mixed agriculture locations (RIVM, 2002). These locations are comparable to the historic land use of De Draai area. Stormwater quality was based on the Rainwater Database (STOWA, 2007). Water quality data of the regional watersystem were obtained from the waterboard Hoogheemraadschap Hollands Noorderkwartier (2008). There were no measurements available for seepage. The only information that was found was that, according to the waterboard, the seepage water contains sulphate. Results are presented in table 4.4 to 4.7. Based on the water quality data, a list of attention substances for local drinking water production was made. The list included pathogens and viruses, algae, cyano bacteria, organic material, chloride, sulphate, ammonium, herbicides and pesticides from internal sources such as direct precipitation, runoff and seepage. Water from regional water system is expected to contain: algae, chloride, sulphate, herbicides and pesticides, other organic micro pollutants. Following the water quantity analysis the following treatment scheme was proposed in this project. For an extended discussion on this treatment scheme, the reader is referred to the full report.

Table 4.8 Proposed treatment steps for local water production and corresponding removal of attention substances (Van den Berg et al., 2008)

Treatment step	Removal of
Micro sieve	Coarse materials
Coagulation – flocculation – flotation	Algae, cyano bacteria, organic material and suspended particles
Double rapid filtration	Ammonium
Nanofiltration	Chloride, sulphate, viruses, pathogens, pesticides
Marble filtration	Hardness
UV disinfection	Viruses, pathogens

4.4 Feasibility rainwater harvesting

The Rainwater module (Van den Berg et al., 2008) was used to evaluate the effectiveness of rainwater harvesting on water demand reduction average, dry and extremely dry years. Table 4.9 presents the results.

Table 4.9 Drinking water demand reduction in case rainwater tanks are applied in all houses (3a) or only in single family houses (3b)

	Average year	Extremely dry year	Dry year
Scenario 3a	27%	15%	23%
Scenario 3b	16%	8%	13%

In case rainwater is harvested and used in all households (scenario 3a) in an average year, drinking water demand decreases considerably. If only the one family houses are equipped with rainwater tanks, the demand is somewhat lower. In an extremely dry year (1921), rainwater harvesting has the potential to contribute to a more self-supporting system. In case all houses are equipped with rainwater tanks, still significant water savings on a yearly timescale are possible. If only the one family houses are equipped with rainwater the drinking water demand decreases with 8%. In a dry year, the potential water savings by rainwater harvesting are higher than in a very dry year. The required amount of water for drinking water production decreases if rainwater tanks are used for the houses.

The results show that rainwater harvesting is a promising technology to reduce drinking water demand. It reduces the dependency of urban areas on the centralised drinking water system. No longer high quality drinking water is used for toilet flushing. Instead rainwater is used for this purpose. Table 4.9 shows that even in an extremely dry year, drinking water demand reduction up to 15% can be achieved.

4.5 Analysis

4.5.1 Technical feasibility

The project results showed that it is technically feasible to produce high quality drinking water from the local urban surface water of the Draai by using local treatment. However, a completely self-supporting system is not possible under dry circumstances. In addition, many risks were identified in the report. The poor expected urban surface water quality and many fluctuations in water quality during critical circumstances require many treatment steps to achieve the water quality standards. Lack of water quality data, in particular with regard to micro pollutants, further introduced unknown risks for using the local urban surface water effectively as a local water source.

In the project a number of risks of local water production were identified. One risk was the transport and storage of water treatment chemicals, including acids, to the residential area. However, compared to daily the transport of highly explosive substances, such as gasoline in residential areas, this risk seems relatively low. Noise from pumping stations and installations in a residential area was mentioned as a potential obstacle in the final report.

A major obstacle of local drinking water production is the collection and transport of concentrate. Because membrane filtration is used to produce drinking water, on a yearly basis 75.000 m³ concentrate is produced. Also the high water temperature was an obstacle. Treatment does not influence the water temperature. This will result in a high drinking water temperature during summer. This problem could possibly be resolved by using the urban surface water as an energy source. This innovation will be discussed in the next chapter.

The use of space was another point of attention that was mentioned in the final report. The total projected use of space for local drinking water production was limited, only 100 m². Also the cost of local drinking water treatment appeared to be relatively low. In a concept version of the final report, the investment costs were estimated at 2.0 million euro, or €710,- per house. The exploitation costs of this treatment plant were estimated at € 1.15/m³. This compares to € 0.6/m³ in case of advanced treatment of surface water on a medium scale (Kiwa, 2006b). The exploitation costs in this project were calculated by the DHV cost estimation program that is commonly applied in the sector. In the project steering group discussions, the costs figures of decentralised treatment were considered risky and inaccurate. Main reason that was given was that these costs did not include cost for personnel, monitoring and transportation of waste. Moreover, the costs might be perceived as low by local elected officials and therefore appeal to them. In the project steering group discussions, this was considered a risk. The final report therefore no longer contained a cost estimation. The final report did mention that a financial comparison between the two systems was not possible, and the exploitation costs of the local system would be considerably higher.

The use of rainwater for toilet flushing appeared to be a promising concept in this study. Drinking water demand reduction range from 8% in an extremely dry year up to 27% in an average year. The costs were estimated at €1250 to €2500 per household. Yearly savings on the drinking water bill amount to € 118 per year for a family of four persons. Risks of rainwater harvesting that were discussed in the project final report include:

- Risk of wrong connection between rainwater supply and drinking water supply
- No control by central authority how rainwater is used in houses
- Insufficient quality of filter systems
- Lack of clear guidelines for cleaning and maintenance

- Increased drinking water demand during dry spells if all rainwater tanks are empty and need to be filled.

To address these risks, it was recommended to test the technology at a small scale, do periodical inspections and develop guidelines for construction and maintenance. In countries such as Australia experience has been built up with guidelines, certification and inspection of systems that utilise alternative water sources (Rijke, 2007). These examples could be used in the Netherlands as well. In this project, it was recommended to build experience with changing roles of stakeholders such as house owners, the water company, the waterboard, contractors and the municipality.

4.5.2 Vulnerability

Main concern in this project was the reliability of local water supply, in particular during incidents. Reliability is expressed in amount of minutes of insufficient supply per house per year. This reliability is probably lower in a decentralised system compared to a conventional system (Van den Berg et al., 2008). However, this conceptualisation of reliability does not take into account the possible simultaneous failure of water supply to all houses in a region (system risk). It is this property of centralised systems, although 'reliable', that makes society vulnerable to disruption.

This was illustrated by an incident on 18 September 2007 in the region of Heerhugowaard. A main water transport pipe broke and more than 100,000 houses had no drinking water for hours (NRC, 2007). While local systems may fail more often, the impacts remain limited to a neighbourhood and do not affect the region. Even relatively unreliable local systems may therefore contribute to reduce the overall vulnerability of society that depends on one water source. The region as a whole becomes less dependent on one source of centralised water supply. Consequently the coping capacity and recovery capacity during droughts increases.

There is a trade off between having an efficient, reliable centralised system that is vulnerable to disruptions, and a local, less efficient system that has a lower overall vulnerability. Another option could be a mixture of both systems. Currently, the trade off between these options is not made in the decision making process at the project level. Instead, technical experts have decided that the centralised system is the best. Their decisions on the future functioning of water supply of cities, although being fundamental to society, are hardly subject to any form of public deliberation. This project was a rare case in the Dutch water supply industry. Mostly, local supply is not taken into account at all. On the other hand, local rainwater harvesting, now being widespread in Belgium, Australia, and other countries, was received positively in this project.

4.5.3 Translation to practice

Climate change and environmental awareness were considerations to study the feasibility of local concepts of water supply in this study. A driver was the national policy to deal differently with rainwater. However, national public health legislation and the lacking receptivity of the water sector were obstacles. The high percentage of surface water in De Draai was a driver to use this system for economic functions. However, the use of the water system as a source of sustainable energy was seen as a more attractive option by the project development team.

Even if technical concepts are technically and economically feasible, there is no guarantee that these concepts will be applied. The sector that is expected to implement these concepts will have to be receptive to these innovations. The Dutch drinking water sector, for good reasons, is proud on the worlds best centralised drinking water factories. Based on experiences in this

project, it seems that the sector will not likely implement decentralised water systems. Although the water experts in this project were well aware of the technical options of decentralised water supply, they were not convinced of the benefits. This is understandable, because there is no perceived sense of urgency of water scarcity. Furthermore, local water resources can be regarded as a competitor for centralised systems. Users of the local system will not financially contribute to the conventional system. Thus, the fixed costs of the conventional network will have to be recovered from a smaller group of users.

Contrary to local water supply, rainwater harvesting was received quite positively. In particular the positive experiences in Belgium and other countries were frequently mentioned as reason to start small scale pilots in the Netherlands. In chapter 9 and 10, the concept of receptivity will be discussed further to develop insight in (lack of) application of technologies that are technically feasible.

In the final report of the project the different scenarios were evaluated by the researchers of the project team. Conventional water supply received the highest score on reliability, supply security, water quantity, and robustness. Rainwater harvesting received the highest score on local resources utilisation and increasing environmental awareness among citizens. Local drinking water production received a good score for local resources utilisation. The construction of a conventional system in combination with rainwater harvesting was recommended. Despite this recommendation, the use of diverse water sources has not yet been taken up by the municipality. Although the project leader tried to include some small scale pilot projects in the development plan, it did not receive priority of the sustainability team of De Draai. The receptivity for these concepts was low. In De Draai, the objective is to realise complete disconnection of stormwater from the sewer system. However, according to international standards, this cannot be regarded an innovation, because it is already standard practice in new developments.

4.6 Conclusion

The use of local water resources can contribute to reducing vulnerability of urban areas. During droughts or disruptions of supply, urban areas no longer depend on one external source. Instead, a portfolio of water resources is used that enables coping with droughts and recovery from them. Climate change will lead to more frequent droughts. Because climate change has many uncertainties, having a diversity of water sources, is an adaptive strategy to make cities more self-supporting and flexible.

In many countries all over the world, rainwater is used for a wide variety of purposes. In this thesis examples from Japan were discussed. In the Netherlands, rainwater is hardly used for residential water use. The most important reasons are: a restrictive national health policy, public health concerns, and the perceived abundance of water in the Netherlands. However, it is acknowledged by national water policy that local water retention and runoff reduction are important. Therefore, in this project the feasibility of realizing a local water supply was studied.

Results showed that an entirely self-supporting water system is not feasible. However, even in a dry year (2003) less than 5% external supply is required on a yearly timescale. Water quality analysis and proposed treatment schemes showed that it is technically possible to produce drinking water from local resources. The use of space and expected costs were relatively low although higher than the costs of a traditional system. Many risks of local water supply were described in this project including transport and storage of chemicals, noise, collection and transport of concentrate, and the risk of micro pollutants. Rainwater harvesting appeared to be a promising technology in this project. The expected drinking water demand reduction was up to

27% on a yearly base. Following this project, rainwater harvesting is still in the process to be included in the development plans of the municipality on a pilot scale.

Based on experiences in this project, there seem to be three most important obstacles to utilisation of local water resources in the Netherlands. The first is the restrictive government policy. The second obstacle is the lack of willingness of the water utilities and municipalities to implement these concepts. The water utility community is not convinced of the benefits of developing local water resources with the exception of rainwater harvesting. Moreover, there is no perceived sense of urgency to use local water resources. The third obstacle is the lack of involvement of other stakeholders in decision making processes about the future of urban water supply. These decisions are currently made by a technical community of experts with hardly any form of public involvement. Consequently, there is no reason to expect that local water resources will be used in the Netherlands on a large scale in the near future.

The observations on obstacles to utilisation of local water resources will be compared with literature in chapter 7 and with results from a national survey among urban water managers in chapters 9 and 10.

5 Case study Heerhugowaard, use of the local urban water system as an energy source⁵

5.1 Introduction

In chapter 1, the multi functional use of urban surface water as source of water, energy and food was presented as an envisaged characteristic of future water systems. This chapter reports on possibilities of using urban groundwater and urban surface water for heating and cooling of buildings by testing the feasibility in a case study. Similar to chapter 4, the author of this thesis actively participated in the case study to develop a perspective on technology application ‘from the inside’. The observations on technology application are described in the discussion section and compared to literature and results of a national survey further in this thesis.

5.1.1 Aquifer Thermal Energy Storage

The need for a more sustainable, less vulnerable energy supply is nowadays widely acknowledged (Yamamoto and Yamji, 2005; IEA, 2005). Water offers many opportunities to reduce the vulnerability of energy supply by using local resources. Possibilities include geothermal and aquifer energy systems (Buitenhuis, 1997; Stojiljković et al., 2006) and the use of water as a direct heat collector (Valan Arasu and Sornakumar, 2006). The combined use of groundwater and surface water as a heat storage and heat collection system has rarely been studied (eg. Nordell and Hellström, 2000).

In the Netherlands, buildings are mainly heated by conventional natural gas based central heating systems (CS), most often on individual house scale. However, increasingly the use of Aquifer Thermal Energy Storage (ATES), for heating and cooling of buildings is applied. ATES is a concept in which the aquifer serves as a medium for temporary heat storage and cold storage. Heating and cooling is delivered by heatpumps to the building. The first ATES project was realised in Dorigny, Switzerland in 1982 and more pilots were started in Denmark (Hørsholm) and the USA (St. Paul, Minnesota) (Snijders, 2005). The total number of ATES projects has grown rapidly. For instance, in 2007 there were over 575 finished ATES projects in the Netherlands (CBS, 2007).

With ATES groundwater is extracted from an aquifer. In winter, when heating is needed, heat is extracted from groundwater. The extracted heat is transferred to the working fluid in the heating system of the house. By using a heat pump, the working fluid in the Low Temperature Heating (LTH) system obtains a temperature of 35-50 °C. Groundwater at the same time is cooled down a number of degrees and infiltrated back into the aquifer. The left part of figure 5.1 elaborates this. During summer, the system works in the opposite way. Heat surplus in houses is extracted by cold groundwater, and groundwater of higher temperature is infiltrated in the aquifer. In the design of ATES system, the design starting point is that the amount of extracted heat to the aquifer is the same as the amount of supplied heat to the aquifer on a long timescale to prevent negative effects.

Benefits of ATES are: a very high efficiency; a high level of comfort and a considerable amount of CO₂ reduction (Holdsworth, 2004). Although ATES is used more and more in the Netherlands, the system still has its limitations. Application of the system requires long term aquifer heat equilibrium to prevent structural aquifer temperature change. Therefore, ATES is mainly used in

⁵ This chapter is based on the following article: De Graaf, R.E., F.H.M. van de Ven, I. Miltenburg, G. van Ee, L.C.E. van de Winckel en G. van Wijk (2008), Exploring the Technical and Economic Feasibility of using the Urban Water System as a Sustainable Energy Source. *Thermal Science* 12 (4), 35-50

office buildings in which heat demand is comparable to cooling demand on a yearly timescale. In other buildings, such as residential buildings, ATES is used less frequently because the heating demand tends to be much higher than cooling demand. In that case, application of ATES results in a structural aquifer temperature decrease. To increase feasibility of ATES in residential districts, expanding it with a heat collection system (ATES+) by extracting heat from surface water for aquifer regeneration could be a promising option.

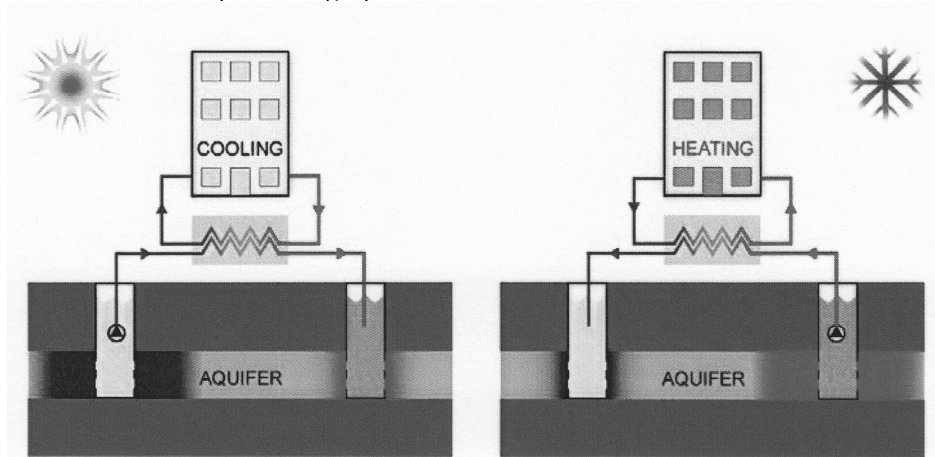


Figure 5.1 Aquifer Thermal Energy Storage (ATES) in summer (left) and winter (right) (IEA, 2005)

5.1.2 Surface water as energy source

The first project in Europe that uses the surface water to heat and cool the building and which is still functioning was finished in Zürich, Switzerland in 1938. The Rathaus building extracts heat and cold from the Limmat river. A proposal to investigate the capacity of using the Amsterdam canal system to heat new urban districts was made in 1946 (Zanstra et al., 1946). However, this investigation was never made because of the abundance of natural gas at the time. The recent urgency to find renewable energy sources has put the urban surface water back on the map of energy sources in the Netherlands. Recently, projects were finished in the cities of Den Bosch (Aparicio, 2008) and Den Haag (2009) and another project will be built in Rotterdam (OVG, 2009). This chapter investigates the possibility of combining the potential of surface water systems and groundwater systems as an energy source. In the municipality of Heerhugowaard in the northern part of The Netherlands, a new urban district of 2816 houses, De Draai, will be developed. More information on the De Draai Heerhugowaard can be found in chapter 4.

The ATES system is supplemented with a surface water heat collection system (ATES+) in order to obtain heat equilibrium on a yearly timescale. The required amount of heat will be extracted from the urban water system in the three summer months, when the temperature is highest. During these months, water quality problems occur that result from eutrophication. These problems are aggravated by a high water temperature. ATES+ could have a positive influence on these problems. It will decrease surface water temperature. Water is pumped from the surface water system. In a heat exchanger heat is transferred from surface water to the groundwater well. Surface water is cooled down and groundwater is heated. Subsequently, cooled water is discharged to the surface water and groundwater with increased temperature is infiltrated. This causes a continuous heat flux from surface water to groundwater which regenerates groundwater with heat and restores aquifer heat equilibrium on a yearly base. Figure 5.2 illustrates the concept.

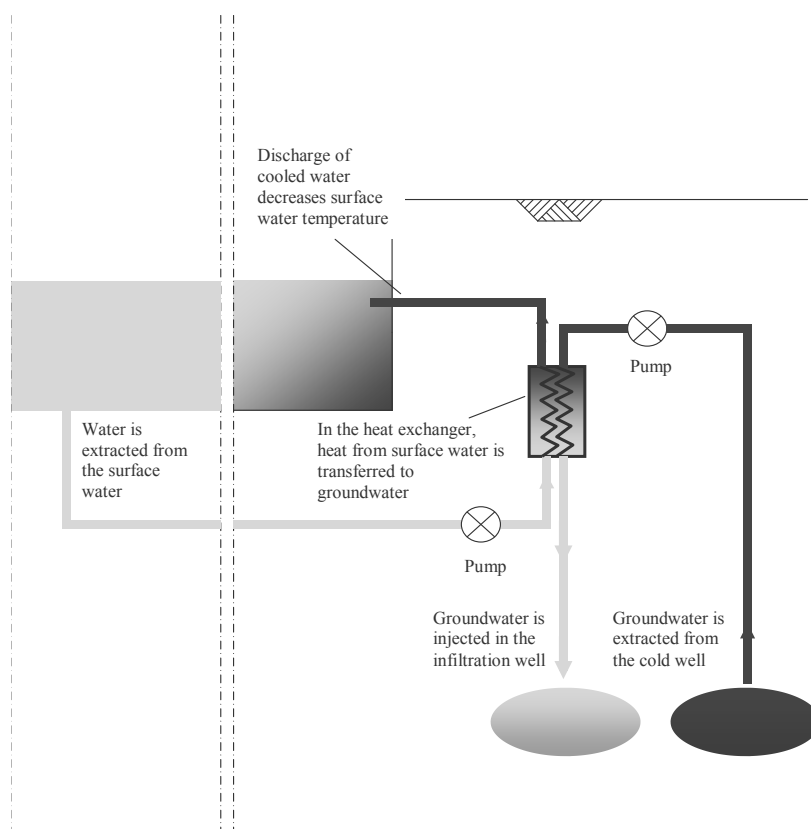


Figure 5.2 Illustration of regeneration of aquifer by surface water heat

5.1.3 Project team approach

Similar to many new urban developments in the Netherlands, De Draai has a high planned proportion of surface water. The main considerations to construct such a high proportion are adapting to climate change and preventing pluvial flooding. The high proportion of surface water puts the ground exploitation under pressure. The development of surface water results in high costs and loss of land that can no longer be sold to property developers. The municipality of Heerhugowaard joined the Transitions SUW project in 2005. Participation in the project was interesting because the project intended to study the feasibility of using the urban surface water for new, more self-supporting functions. With new economic functions, urban surface water would no longer be a loss on the development balance. Instead, it would be an added economic value. In the project plan, one concept that was specifically mentioned was the use of urban surface water as a source of sustainable energy.

To make the connection between water management and energy supply, the project leader of the Transitions SUW project invited sustainable energy consultants Ecofys to join the consortium. They agreed to join and would bring their knowledge of energy systems to the project. The research plan for this case study was finished in March 2006. The author of this thesis participated in this research on behalf of TU Delft. Next to TU Delft and Ecofys, Tauw consultants joined the project. Their specific knowledge on groundwater and ATEs was an essential component for this study on ATEs+. The steering group consisted of the Waterboard Hollands Noorderkwartier and the Municipality of Heerhugowaard.

It took about half a year before the research started. The preparation of a common plan that was acceptable to all stakeholders took much time. In particular, the nature of the project was new for many of the project partners. It was partly research, partly a consultancy project, with co financing from all the partners. In September 2006 all the paperwork was finished and the project started. Tauw led the part on groundwater feasibility, Ecofys studied the energy demand of the new project, and TU Delft was responsible for studying the effects on surface water and integration of the three parts.

After the project started, the long preparation time proved to be valuable. The project partners had specialised knowledge on parts of the study. The first results were finished quickly and the components were integrated. The heat demand was used in calculations on groundwater. Later, these results were used to study the effects on surface water. The final project report was finished in January 2007.

5.2 Methodology

To determine the technical and economic feasibility of the water system as a sustainable energy source (ATES+), a couple of steps were taken by the researchers. First, energy demand and CO₂ emission of the new residential district were calculated. Heat and cooling will be supplied to houses by use of ATES+. The yearly difference between heating and cooling demand determines the aquifer heat shortage. Second, feasibility of the local geohydrological situation was determined by analyzing previous surveys and borehole data. Third, temperature effects and oxygen content effects on the surface water system were determined. Fourth, the economic feasibility was determined, climate aspects were investigated and a comparison with CS was made.

5.2.1 Heat demand estimation method

Heating and cooling in houses is used for indoor climate control and heating of tap water. Heat demand is determined by the quality of insulation, typology of the house, and regional climate conditions. The Dutch government has issued standards for insulation, the Energy Performance Coefficient (EPC). For new houses the EPC should be equal or lower than 0.8. The typology of the houses in De Draai consists of 19 different types, ranging from single apartments to one family houses. These houses were classified according to five reference house types of SenterNovem (2006). Reference houses have standardised energy demands and CO₂ emissions that were used to calculate heat demand. These figures were based on Dutch climate conditions, housing data and the Dutch national energy infrastructure including the natural gas distribution system and the electricity grid. In this research, reference houses were used to calculate energy demand and CO₂ emissions in the CS and ATES+ system in order to enable comparison. The CO₂ reductions for ATES+ were calculated based on prevented natural gas use. To determine the required maximum heating capacity and cooling capacity for houses P_h and facilities P_s , equation(5.1) and equation(5.2) were used (NVOE, 2006).

$$P_h = f_{co} n P_{max,ah} \quad (5.1)$$

$$P_s = \frac{H_y}{t_{fl} 3600} \quad (5.2)$$

With:

P_h	= Maximum total heating power for houses [kW]
f_c	= Correction factor [-]
n	= Number of houses [-]
$P_{\max,ah}$	= Maximum heating power average house [kW]
P_s	= Maximum total heating power for services [kW]
H_y	= Total yearly service heating demand [kJ]
t_n	= Full working load equivalent [hours]

The maximum required groundwater extraction was determined by the heating and cooling capacity, the temperature difference and the Coefficient of Performance (*COP*) of the heatpump, see equation (5.3) (NVOE, 2006).

$$Q_{\text{gw,max}} = \frac{3600(P_h + P_s)(1 - \frac{1}{\text{COP}})}{c_{\text{water}} \cdot \Delta T \cdot \rho_{\text{water}}} \quad (5.3)$$

With:

$Q_{\text{gw,max}}$	= Maximum groundwater extraction [m^3h^{-1}]
<i>COP</i>	= Coefficient of performance [-]
c_{water}	= Heat capacity of water [$\text{J}/\text{kg}^{-1}\text{C}^{-1}$]
ΔT	= Temperature difference groundwater [$^{\circ}\text{C}$]
ρ_{water}	= Specific density of water [kgm^{-3}]

5.2.2 Groundwater feasibility method

No net extraction of groundwater takes place, only extraction of heat. The local groundwater feasibility to supply the design discharge was determined by soil and aquifer characteristics (type, profile, quality) and available space to locate boreholes for extraction and infiltration. Soil and aquifer data were from the groundwater map of the Netherlands (Speelman and Houtman, 1979) data on four boreholes information from the geohydrological database REGIS (TNO, 2006a) and from the national geological DINO database (TNO, 2006b).

Space is needed to locate boreholes for extraction and infiltration of the required design discharge. The number of boreholes was determined by the maximum allowable borehole velocity, borehole diameter and permeability. For infiltration, the maximum allowable borehole groundwater velocity was calculated by equation (5.4) that is based on the work of Buik and Willemsen (2002). The Membrane Filtration Index (*MFI*) gives the specific clogging capacity of the groundwater [s/l^2] in terms of how much time is required for a litre of water to flow through the filter and how this number increases with each litre of water. With the specific clogging velocity v_{cl} of the groundwater, permeability k and the full load equivalent of the heatpump, the maximum allowable velocity on the borehole is given by equation (5.4).

$$v_{\max} = 1000 \left(\frac{k}{150} \right)^{0.6} \sqrt{\frac{v_{cl}}{2MFI t_{fl}}} \quad (5.4)$$

With:

v_{max}	= Maximum allowable velocity on borehole [mhour ⁻¹]
k	= Permeability [mday ⁻¹]
v_d	= Specific clogging velocity [myear ⁻¹]
MFI	= Membrane Filtration Index [s ^{1/2}]

For extraction, the maximum allowable borehole velocity is given by equation (5.5) (NVOE, 2006).

$$v_{max} = \frac{k}{12} \quad (5.5)$$

The maximum allowable velocity on the borehole, borehole radius r and the maximum required groundwater extraction determine the total required filter length b which can then be calculated by equation (5.6).

$$v_{max} = \frac{Q_{gw,max}}{2\pi rh} \quad (5.6)$$

With:

b	= Total filter length [m]
r	= Radius of borehole [m]

5.2.3 Surface water heat balance method

Two types of water system effects were distinguished: temperature effects and oxygen content effects. To quantify temperature effects on the surface water system, a heat balance spreadsheet model on a monthly base was made. The main purpose of this study was to quantify the capacity of surface water to supply heat to the groundwater in order to achieve aquifer heat equilibrium on yearly basis. For that purpose a heat balance was used to quantify surface water temperature effects resulting from heat extraction. The heat balance of a water body is given by equation (5.7) (Sweers, 1976).

$$H_t = H_{sl} + H_a + H_l + H_e + H_c + H_f \quad (5.7)$$

With:

H_t	= Net change of heat per unit of area [Wm ⁻²]
H_s	= Incoming net solar radiation [Wm ⁻²]
H_a	= Incoming atmospheric radiation [Wm ⁻²]
H_l	= Back radiation of lake [Wm ⁻²]
H_e	= Evaporation heat flux [Wm ⁻²]
H_c	= Conduction heat flux [Wm ⁻²]
H_f	= Heat flux from inflowing/outflowing water in the system [Wm ⁻²]

The sun is constantly heating the earth and water surfaces. Direct solar radiation is referred to as short wave radiation (wavelength < 4μm). Only a part of the incoming solar radiation eventually reaches the earth because of clouds, dust particles and reflection. There are many empirical

relations to describe the relation between incoming solar radiation and net solar radiation. However, since the net solar radiation in the Netherlands is measured by the Royal Meteorological Agency (KNMI, 2006), these measurements were used as an input for the model.

Solar radiation causes heating of the atmosphere that subsequently results in atmospheric elements emitting (long wave) atmospheric radiation. The amount of radiation emitted from these elements is determined by the temperature, cloud density and vapour pressure. The law of Stefan Boltzmann gives the following general relation in equation (5.8).

$$H_a = \varepsilon \sigma_{SB} (T_a + 273)^4 \quad (5.8)$$

With:

ε	= Emissivity of the atmosphere [-]
σ_{SB}	= Constant of Stefan Boltzmann [$\text{Wm}^{-2} \text{K}^{-4}$]
T_a	= Air temperature [$^{\circ}\text{C}$]

The emissivity ε varies considerably depending on the condition of the atmosphere. The following expression (9) for emissivity was proposed by Edinger and Geyer (1965) that was based on the work of Brunt (1932).

$$\varepsilon = a + b\sqrt{p_a} \quad (5.9)$$

With:

p_a	= Atmospheric vapour pressure [Pa]
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In which a and b are constants that depend on air temperature, and the ratio of measured atmospheric radiation and the theoretical atmospheric radiation. The atmospheric vapour pressure is given by equation (5.10) (Boderie and Dardengo, 2003).

$$p_a = 6,112 \cdot 10^{\left(\frac{7,5 \cdot T_a}{237,7 + T_a}\right)} \quad (5.10)$$

Several researchers have investigated the coefficients in Brunt's formula. Table 5.1 provides an overview (Iziomon et al., 2003). For Dutch circumstances, the following relation (11) was proposed by Wiggers et al. (1998). In this formula the emissivity is a function of cloud coverage and atmospheric vapour pressure.

$$\varepsilon = 0.74 \cdot (1 + 0.17C_c) + 0.0045(1 - C_c) \cdot p_a \quad (5.11)$$

With:

C_c	= Cloud coverage as a fraction of 1 [-]
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This relation is comparable with the Brunt formula (Boderie and Dardengo, 2003), the emissivity difference under Dutch circumstances is less than 3%.

Table 5.1 Overview of Brunt's coefficients (Iziomon et al., 2003)

Investigator	Location	a	b [hPa ^{-1/2}]
Brunt (1932)	Benson (UK)	0.55	0.065
Monteith (1961)	Kew (UK)	0.53	0.065
Swinbank (1963)	Australia	0.64	0.037
Sellers (1965)	22 locations world wide	0.61	0.048
Berger et al. (1984)	France	0.66	0.040
Berdahl and Martin (1984)	Six locations in the USA	0.56	0.059
Heitor et al. (1991)	Lisbon (Portugal)	0.59	0.044
Iziomon et al. (2003)	Bremgarten (Germany)	0.6	0.064
Iziomon et al. (2003)	Feldberg (Germany)	0.5	0.066
Variability (%)	Above locations	13	32

The back radiation of the lake is the heat emitted from a water body. The process can be physically described by the law of Stefan Boltzman, the only determining factor is the water temperature T_w and in this case $\epsilon = 0.97$ (Sweers, 1976; Boyd and Kasper, 2006). The resulting heat flow is presented in equation (5.12).

$$H_l = -\epsilon\sigma_{SB}(T_w + 273)^4 \quad (5.12)$$

With:

T_w = Water temperature [°C]

By the process of evaporation, heat is extracted from surface water. By condensation heat will be delivered to the surface water. The evaporation flux is determined by a wind velocity function and the difference between the actual vapour pressure and the saturation vapour pressure. The following expression (13) describes the heat extraction resulting from evaporation (Sweers, 1976).

$$H_e = f(v_{wind}) \cdot (p_s - p_a) \quad (5.13)$$

With:

$f(v_{wind})$ = Empirical wind velocity function [Wm⁻²HPa⁻¹]

v_{wind} = Wind velocity [ms⁻¹]

p_s = Saturation vapour pressure [Pa]

There are many empirical approximations of the wind velocity function in different regions. An overview is presented in Boderie and Dardengo (2003). The formula of the World Meteorological Organisation (WMO, 1966) has a good applicability for moderate climates (Van Mazijk et al., 2002). For the saturation vapour pressure many good approximations are available that yield almost identical results (Boderie and Dardengo, 2003). The wind function and saturated vapour pressure were computed as equation (5.14, 5.15).

$$f(v_{wind}) = 3.68 + 2.65 \cdot v_{wind} \quad (5.14)$$

$$p_s = 23.4 \cdot 1.062^{(T_w - 20)} \quad (5.15)$$

5.2.4 Conduction heat flux

The conduction heat flux, or sensible heat flux, is the heat flux that is driven by the temperature differences between the water temperature and the air temperature. Bowen (1926) found that heat conduction and evaporation heat flux are proportional with Bowen ratio B . A general expression is given by equation (5.16, 5.17). The Bowen ration is determined by the psychrometric constant γ and the difference between water temperature and air temperature, and the difference between saturation vapour pressure and atmospheric vapour pressure.

$$H_c = B \cdot H_e \quad (5.16)$$

$$B = \gamma \frac{T_w - T_a}{p_s - p_a} \quad (5.17)$$

With:

B = Bowen ratio [-]

γ = Psychrometric constant [0.55 hPaK⁻¹]

Substituting eqs. (5.14, 5.16, 5.17) in equation (5.13) gives the following expression (5.18) for conduction heat flux:

$$H_c = (2.02 + 1.46v_{wind})(T_a - T_w) \quad (5.18)$$

5.2.5 Heatpump extraction flux

An additional heat balance component in this case is extraction of heat from surface water. This amount is equal to the total annual required regenerated heat demand divided by the amount of extraction days divided by the total surface of the water system. Equation (5.19) presents the relation.

$$H_{hp} = \frac{(P_h + P_s)_{heating} - (P_h + P_s)_{cooling}}{24 \cdot 3600 \cdot d \cdot A_{sw}} \quad (5.19)$$

With:

H_{hp} = Heat pump extraction flux [Wm⁻²]

d = Total period surface water heatpump operation [days]

A_{sw} = Total area of surface water [m²]

Because the water system under consideration is a closed system, heat flux H_f resulting from inflowing and outflowing water in the system is equal to zero. Of the heat balance, components only surface water radiation, evaporation heat flux and heat conduction are (partly) determined by water temperature. Because all other factors are known, the surface water equilibrium temperature were calculated iteratively by a spreadsheet model for a situation where heat is

extracted (ATES+) and in a situation where no extraction takes place (CS). Table 5.2 summarises the heat balance components.

Table 5.2 Heat balance components

Component [Wm ⁻²]	Method
Solar radiation	Average of nearest weather stations, De Kooy and Schiphol
Atmospherical radiation	$H_a = \beta\sigma_{SB}(T_a + 273)^4$
Lake radiation	$H_l = -\beta\sigma_{SB}(T_w + 273)^4$
Evaporation and condensation heat flux	$H_e = (3.68 + 2.65v_{wind})(p_a - p_s)$
Heat conduction to/from atmosphere.	$H_c = (2.02 + 1.46v_{wind})(T_a - T_w)$

5.2.6 Oxygen content effects

By extracting heat from the surface water system, water temperature is decreased. Physical reaeration is the flux of oxygen from the atmosphere to the surface of the water system. Reaeration is determined by the oxygen deficit: the difference in saturation oxygen content and the actual oxygen content. The saturation oxygen content depends on the water temperature. Physical reaeration is determined by the oxygen deficit and the physical reaeration coefficient, it is described by equation (5.20) (Radtke et al., 1998).

$$\frac{dD}{dt} = -k_2 \cdot D \quad (5.20)$$

With:

D = Oxygen deficit [mg l⁻¹]

k_2 = Physical reaeration coefficient [d⁻¹]

Because the physical reaeration coefficient k_2 is constant for small temperature changes, the increase in oxygen flux is proportional to the increase in oxygen deficit D . Further increase of oxygen flux can be expected by an increased surface water circulation velocity. This will be caused by extracting and discharging water for heating and cooling purposes. Equation (5.21) describes that the physical reaeration coefficient will increase with the canal flow circulation velocity that results from water discharge to the system (Pakhurst and Pomeroy, 1972).

$$k_2 \sim v^{3/8} \quad (5.21)$$

With:

v = Circulation velocity of canal flow [ms⁻¹]

5.2.7 Economic feasibility method

To compare the combined cost of investments and exploitation various methods are available. Calculation of the Net Present Value NPV and Internal Rate of Return IRR are often used for this purpose. The NPV discount future expenditures and income X in year T to their present value (Weil and Maher, 2005) the relation is expressed by equation (5.22).

$$NPV = \sum_{t=0}^T \frac{X_t}{(1+i)^t} = \frac{X_0}{1} + \frac{X_1}{1+i} + \frac{X_2}{(1+i)^2} \dots + \frac{X_T}{(1+i)^T} \quad (5.22)$$

With:

NPV	= Net present value [euro]
i	= Discount rate [-]
X_t	= Income or expenditure in year t [euro]

The IRR indicates at which discount rate a project becomes profitable. The discount rate at which the NPV of a project is zero is equal to the IRR . The higher the IRR the more feasible a project is from an economic point of view because in that case the project can be executed by even a very high discount rate. The IRR was determined by iteration in equation (5.23) (Weil and Maher, 2005).

$$\sum_{t=0}^T \frac{X_t}{(1+IRR)^t} = NPV = 0 \quad (5.23)$$

With:

IRR	= Internal rate of return [-]
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A comparison was made between a conventional system (CS) with gas based central heating and the system in which the water system is the source for sustainable energy (ATES+). For this comparison, the investment and exploitation costs of the total system were taken into account including, extraction and infiltration, distribution and the heatpump installation at household level.

5.2.8 Design specifications, constants and assumptions

To be able to determine the feasibility of the concept, design specifications were used. For other factors, assumptions were made for heat demand, groundwater, surface water and economic aspects based on reference projects and analysis of the local situation. Design specifications (DS), constants (C) and assumptions (AS) are summarised in tables 5.3- 5.5. Design specifications were obtained from the system engineers that collaborated in this research. Furthermore, the water system was assumed to behave like a fully mixed system, because the water system in De Draai is designed as a series of connected small lakes in which mixing circulation pumps will be installed. Monthly water temperature was assumed constant. In reality, water temperature fluctuations around the average occur, however, these do not affect the monthly heat balance and the influence of heat extraction on the average water temperature. Heat sources that were neglected in the heat model are turbulence, heat transport by precipitation, heat conduction to and from the bed sediments and biological and chemical degradation processes. However, the contribution of these processes to the equilibrium temperature is only small (Sweers 1976; Van Mazijk et al., 2002).

Table 5.3 Design specifications and assumptions for heating demand and groundwater

<i>Heating demand</i>	Unit		Type
Full load equivalent	Hours	1200	DS
Coefficient of Performance (COP)	-	4.7	DS
Max heating power average single house	kW	7	DS
Max cooling power average single house	kW	3	DS
ΔT groundwater	$^{\circ}\text{C}$	6	DS
<i>Groundwater</i>			
Specific clogging density	my^{-1}	0.1	AS
MFI	sl^{-2}	2	AS

Table 5.4 Design specifications, constants and assumptions for surface water

<i>Surface water</i>	Unit		Type
Extraction discharge	m^3s^{-1}	0.4	DS
Heat capacity of water	$\text{kJkg}^{-1}\text{C}^{-1}$	4.18	C
Specific density of water	kgm^{-3}	1000	C
Average oxygen content	mg l^{-1}	5	AS
Constant of Stefan Boltzman	$\text{Wm}^{-2}\text{K}^{-4}$	$5.67 \cdot 10^{-8}$	C
Emissivity ϵ of the water system	-	0.97	C

Table 5.5 Design specifications and assumptions for economy

<i>Economy</i>	Unit		Type
Discount rate	%	6	AS
Inflation	%	2	AS
Electricity annual price increase	%	3	AS
Natural gas annual price increase	%	5	AS
Technical lifetime household installation	y	15	DS
Technical lifetime distribution network	y	30	DS

5.3 Results

5.3.1 Heat demand and CO₂ emission

Table 5.6 gives the heat demand, required heating and cooling power of the total residential district. This determined total groundwater extraction, yearly groundwater extraction and yearly heat shortage of the aquifer. Moreover, CO₂ emissions are presented. As can be observed, ATES+ resulted in an annual CO₂ emission of 2750 tons compared to 6750 tons in case of a conventional system; this was equal to a CO₂ reduction of 60%.

Table 5.6 Heat demand, groundwater extraction and emissions

	Unit	Heating	Cooling
Number of houses	-	2,816	
Total demand	GJy ⁻¹	106,657	21,331
Emission CS	10 ³ kggy ⁻¹		6750
Emission ATES+	10 ³ kggy ⁻¹		2750
Yearly heat shortage aquifer	GJy ⁻¹		85,325
Correction factor	-	0.9	0.9
Total Power	kW _{th}	18,776	8,047
Max. groundwater extraction	m ³ h ⁻¹	2,119	1,155
Total groundwater extraction	m ³ y ⁻¹	2,543,210	1,386,060

5.3.2 Groundwater feasibility

The local soil profile is schematised in table 5.7. Further analysis of local data showed that the separating layer between the first and the second aquifer was absent at the location of De Draai. Permeability was about 20 mday⁻¹. Moreover, the first aquifer was brackish, gradually changing to salt from a depth of 40 meters. Therefore, the first and second aquifers from a depth of 20 up to 60 meter were considered suitable to place filters to extract and infiltrate water. Mixing of fresh and brackish water was not expected to occur because there was no fresh water in the extraction zone. No occurrence of mixing is a precondition for obtaining legal permission for ATES in the Netherlands. Space was needed to locate boreholes for extraction and infiltration of the required design discharge. The number of boreholes was determined by the maximum allowable borehole velocity, borehole diameter and permeability. The available area of 1,500,000 m² was sufficient to locate 14 wells with mutual distance of 225 m. Table 5.8 summarises the results.

Table 5.7 Schematised regional and local soil profile

Regional situation				Local situation	
Depth under terrain level (m)	Soil types	Geological Formation	Soil layer	Depth under terrain level (m)	Soil types
0 - (15 to 20)	Fine sand, clay and peat	Westland	Covering layer	0-4 4 – (15 to 20)	Moderate fine sand and sandy clay Moderate fine to moderate coarse sand
(15 to 20) - >120	Moderate to coarse sand	Twente, Kreftenheye, Drenthe, Eem, Urk, Sterksel	First and second aquifer	(15 to 20) – 35 35 – 37 37 - >60	Moderate coarse to coarse sand Sandy clay Moderate fine to moderate coarse sand

Table 5.8 Required filter length and number of wells

Design extraction	m ³ h ⁻¹	2,119
Maximum allowable extraction velocity	mh ⁻¹	1.7
Maximum allowable infiltration velocity	mh ⁻¹	4.5
Total filter length	m	495
Required number of wells	couples	14
Mutual distance wells	m	225
Required surface	m ²	1,438,000

5.3.3 Surface water feasibility

Table 5.6 shows that the yearly expected heat shortage in the aquifer under the residential district was 85,325 GJ. This was the amount that was to be extracted from the urban surface water system. Results from the heat balance model enabled comparison between CS and ATES+. As a result, evaluation of the net temperature decrease was possible. Tables 5.9 and 5.10 show the temperature decrease that results from heat extraction was 1.5 to 1.6 °C. The corresponding oxygen saturation content increased. Two driving forces determined the physical reaeration flux: (1) the oxygen deficit, and (2) the flow velocity. In case of an oxygen content of 5 mg/l, the oxygen deficit increased with 8.7% in June, 4.6% in July and 4.7% in August. The extraction and discharge of water for heating and cooling resulted in a twofold increase of circulation flux compared to CS in which only a circulation pump was installed. This caused a proportional increase in flow velocity. Consequently, physical reaeration increases with 36% to 41%, following equation 21.

Table 5.9 Surface water temperature results of a conventional system

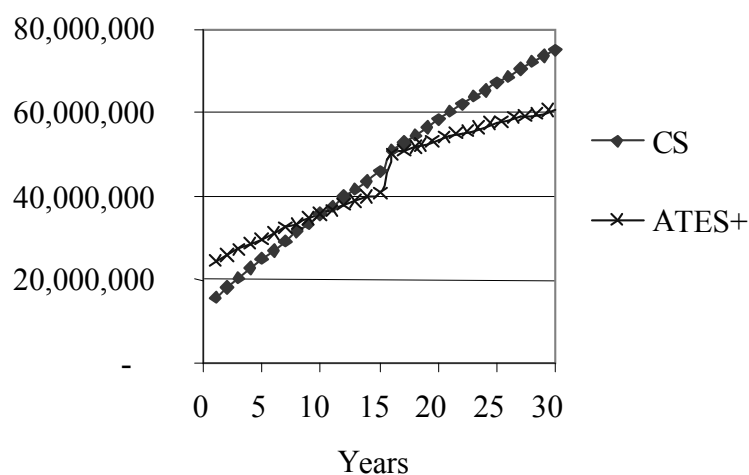
	Unit	June	July	August
Solar radiation	Wm ⁻²	203.3	193.9	166.5
Atmospherical radiation	Wm ⁻²	312.3	337.7	338.4
Lake radiation	Wm ⁻²	-388.5	-400.9	-397.1
Evaporation	Wm ⁻²	-105.4	-109.2	-94.3
Conduction	Wm ⁻²	-21.1	-21.0	-13.2
Heat extraction	Wm ⁻²	0	0	0
Water temperature	°C	16.9	19.2	18.5
Oxygen saturation content	mg/l ⁻¹	9.6	9.3	9.4
Oxygen deficit	mg/l ⁻¹	4.6	4.3	4.4
Circulation discharge	m ³ /s	0.1	0.1	0.1

Table 5.10 Surface water temperature results of the ATES+ system and a comparison

	Unit	June	July	August
Solar radiation	Wm ⁻²	203.3	193.9	166.5
Atmospherical radiation	Wm ⁻²	312.3	337.7	338.4
Lake radiation	Wm ⁻²	-378.0	-392.8	-388.5
Evaporation	Wm ⁻²	-75.7	-77.8	-62.8
Conduction	Wm ⁻²	-6.42	-7.61	0.88
Heat extraction	Wm ⁻²	-52.9	-52.9	-52.9
Water temperature	°C	15.3	17.7	16.9
Oxygen saturation content	mg/l ⁻¹	10	9.5	9.7
Oxygen deficit	mg/l ⁻¹	5	4.5	4.7
Circulation discharge	m ³ /s	0.2	0.2	0.2
Comparison (ATES+ vs. CS)				
Net temperature decrease	°C	1.6	1.5	1.6
Oxygen deficit increase	%	8.7	4.6	4.7
Increase k ₂	%	30	30	30
Total physical reaeration increase	%	41	36	39

5.3.4 Economic feasibility

The investment costs of the ATES+ were considerably higher than CS. However, the exploitation costs were lower because of energy savings. In addition, stricter energy standards for new houses will lead to increasing investments for houses that apply the conventional system. Figure 5.3 shows the *NPV* of ATES+ was lower than the *NPV* of the conventional system. After 30 years of technical lifetime the expected difference in costs was 20%. The step for ATES+ after 15 years is caused by the required renewal of heatpumps. Also the *IRR* calculations are positive for the ATES+. The *IRR* was 15% at the end of the technical lifetime. This means that the project was feasible at a discount rate of 15%.

**Figure 5.3** Development of the net present value of the two systems

5.4 Analysis

5.4.1 Technical feasibility

The results showed that application of ATES+ in 'De Draai' is preferable to CS based on water system effects, cost effectiveness and CO₂ emission. Recent climate impacts research on surface water systems, indicate that climate change will result in a water temperature increase of 0.8 to 2.8 °C in the Netherlands (Loeve et al., 2006). This will cause increased water quality problems, such as anaerobic conditions and eutrophication. Decreasing the water temperature by using ATES+ potentially mitigates effect of climate change on urban surface water systems.

Although the feasibility of the ATES+ concept was demonstrated for one residential project in the Netherlands, it is applicable elsewhere. Considering the fact that more than 85% of the Netherlands is suitable for aquifer heat storage and that new developments have an increasing amount of surface water, this concept has high potential. Internationally, this concept has potential for cities in alluvial plains where aquifers have been formed and surface water such as lakes, rivers or canals are present.

Limitations of the results can be subdivided in water system effects and economic effects. For groundwater feasibility, assumptions were made for the specific clogging velocity and *MFI*. These assumptions were based on comparable projects in the Netherlands and were used to calculate the critical infiltration velocity. The assumptions made in table 5.3 were conservative design standards. For instance, *MFI* is generally below 2 sl⁻² in Dutch circumstances (IF Technology, 2001), whereas the specific clogging velocity is generally higher than 0.1 myear⁻¹. As a result, the required surface in table 5.8 is an upper bound estimate.

The assumption made in table 5.4 with regard to the actual oxygen content corresponded with the minimum target level of the local waterboard in correspondence with the European Water Framework Directive (EU, 2000). This was a lower bound assumption: higher oxygen content will result in a higher relative increase of the oxygen deficit by decreasing the temperature. Table 5.10 indicated that physical reaeration increased with 36% to 41% by applying ATES+. This was expected to have beneficial effects on water quality. However, conclusions about the resulting oxygen content could not be made within the scope of this research. To estimate oxygen levels, a detailed water quality investigation should be undertaken in follow up research that includes biological reaeration processes in addition to physical processes.

The economic assumptions were based on conservative estimates. For instance, the annual natural gas price was assumed to be 5%. Over the past 10 years, the gas price increase in the Netherlands was on average 8%, for electricity the increase was 7% (CBS, 2007). Considering the expected lifetime of the system and the unknown energy price development in the future, rather safe assumptions were made. Therefore, the long term economic feasibility of the ATES+ system is probably more favourable than was reported here.

5.4.2 Vulnerability

ATES+ makes the construction a natural gas distribution network obsolete in a new urban development. For cooking, electricity can be used. As a result, the district does not entirely rely on finite fossil resources and international gas distribution networks that might be disrupted in the future by geopolitical tensions, incidents or terrorism. Price fluctuations on the international energy market have a small impact on the heat and cooling system of De Draai. Local energy supply can be regarded as an adaptive strategy to the uncertainties of the global energy market.

The vulnerability of this district is lower than in case of a conventional system. However, still electricity is needed to operate the system.

5.4.3 Translation to practice

Climate change, energy scarcity and environmental awareness were important drivers to execute this study. The long existing ambition of the municipality to become the first CO₂ neutral municipality in the Netherlands also created a window of opportunity for this concept. In addition, the municipality already had experience with another innovative urban development, Sun City, which was in the final stage of development during this study. At project level, a visionary and enthusiastic project leader who was open to new concepts was a driver. Also the high percentage of surface water in De Draai was an incentive to study new economic functions.

The project development team of De Draai was quite positive about the concept of ATES+. An obstacle for large scale implementation of this concept was the rather high investments costs. Although the exploitation costs were considerably lower because of energy savings, only residents benefit from this. Project developers face higher investment costs. As a result, commercial project developers are not likely to contribute to wide scale application of the system.

The project was finished and presented to the municipality and waterboard in January 2007. The report led to a discussion on competing alternatives in the municipality. Using the asphalt roads as a solar collector was considered more attractive by some members of the project team. More experience and example projects were available for asphalt solar collectors. In addition, subsidies could be obtained for this concept. The discussion led to a new study that was executed by Ecofys. This study compared the two alternatives. It appeared that the alternatives were comparable on most criteria. However, the ATES+ concept received a much higher score on water quality improvement.

On 25 September 2007, the municipal board of Heerhugowaard chose the alternative of ATES+. The starting document of the legally required Environmental Impact Assessment was published in the beginning of 2008. The decision to start an Environmental Impact Assessment (EIA) was made by the municipal board on 25 November 2008. The EIA committee finished their advice in March 2009. In general, the committee approved the concept. Only one remark was made with regard to the technical standards of buildings. The energy efficiency of the ATES+ system is that large, that even with lower technical standards, the legal obligations for energy efficiency of the district would be achieved. However, lowering the technical standards was not considered desirable by the committee.

Next to the environmental assessment, a market scan was done by the municipality to study market receptivity. A couple of large companies were interested. Notwithstanding the commercial interest, the municipality is studying the feasibility of starting a municipal energy company. Given the high IRR of the system, there is certainly a commercially attractive potential. This could contribute to the founding of a viable energy company in order to achieve the target of a CO₂ emission neutral municipality in 2027.

In March 2009, the municipality requested a permit from the Province Government for the system. The permit is expected in 2009.

5.4.4 Follow up research: Paleiskwartier Den Bosch

After the study in Heerhugowaard, TU Delft and Deltares started a follow up research in the only finished project using the ATES+ system at that moment, Paleiskwartier Den Bosch (Aparicio, 2008). In this project, a pond on top of a parking garage is used as a solar collector to regenerate

heat in the aquifer of the ATEs system. Similar to the 'blue roofs' in New York City (2009), this pond can also be used for stormwater detention.

The study consisted of a modelling study and measurement campaign. The objective of the study was to develop insight in heat fluxes in the urban surface water, to quantify heat fluxes in the urban surface water, and quantify the effects of heat extraction for ATEs+.

During 14 days in the summer of 2008, the ponds water temperature was measured using the Distributed Temperature Sensing Technique (DTS) with 900 meters of fibre-optics cable. A meteorological station was located in the pond to measure atmospheric variables. The study results showed that the pond with an area of 11,200 m² provides sufficient heat for 132 apartments. The required surface water area per apartment is 85 m². This is comparable to the results of De Draai. In this project, 207,000 m² of water area provides sufficient heat for 2816 houses. The required surface water area per house is 73 m².

5.5 Conclusion

This chapter demonstrated that a new residential district in the Netherlands can be self reliant for heating and cooling purposes by Aquifer Thermal Energy Storage supplemented with surface water heat collection (ATEs+). By cooling the surface water with 1.5-1.6°C in three summer months, enough heat is collected to compensate full residential heating and cooling demand. This makes sustainable energy supply by Aquifer Thermal Energy Storage (ATEs) possible in residential areas. Until now, this system has mainly been applied in office buildings. With the concept of ATEs+, fossil fuels are no longer required to heat houses. Therefore, the urban district is less vulnerable to international developments on the energy market. However, electricity remains necessary to operate the system.

Considerable energy savings and a CO₂ emission reduction of 60% are achieved. Water quality and ecological improvement take place because a lower temperature results in increasing oxygen content. Moreover, the expected water temperature increase by climate change can be partially prevented. The concept is also economically feasible. Considering the full lifetime and all investment and exploitation costs, the concept is more profitable than a conventional system. Therefore, this concept has the potential to contribute to the societal objective to achieve a more sustainable, self-reliant energy supply.

Based on experiences and observations in this project, a number of reasons seem important for the application of an innovation. The ambition of the municipality and their experience with another innovative project, created a window of opportunity for this concept. Also the project team was open to new ideas. The use of urban water system for energy supply was a potential solution for the financial feasibility problem of the project exploitation that was threatened by the high percentage of surface water. The concept won from a competing alternative because of positive water quality impacts. These observations will be compared with literature in chapter 7 and with results from a national survey among urban water managers in chapters 9 and 10.

6 Case study Netherlands: Using the surface water for urbanisation

6.1 Introduction

Chapter 1 identified the use of urban surface water for multiple functions and flexible infrastructure as properties of envisaged future water systems. Chapter 2 mentioned flood proof urbanisation as a way to reduce vulnerability by increasing coping capacity, recovery capacity and adaptive capacity. This chapter is about the use of surface water for urbanisation, or floating urbanisation. Floating urbanisation has recently received much attention of researchers, politicians and media. It is a flexible and reversible mode of urbanisation and therefore responds to the societal objective to increase the capacity to adapt the built environment to climate change. This innovation is expected to reduce vulnerability of urban areas by reducing flood impact. In addition, the lack of space in lowland delta areas could be addressed by multifunctional use of space combining water storage and housing by floating, or amphibious, urbanisation.

The focus of this chapter is not testing the technical feasibility in a case study. The technical feasibility is shown by describing finished projects. Instead, this chapter is an exploration study how in the Netherlands, floating urbanisation is developing from a niche market of houseboats, to a more developed industry that works on integrated urbanisation plans. As such, this chapter aims to contribute to the development of insight in mechanisms that influence the diffusion of technical concepts. The observations in this chapter are based on reviewing the literature on floating urbanisation, and the personal experience of the author in floating urbanisation projects as reflective practitioner. The mechanisms that are described in this chapter will be further tested and grounded in part 2 of this thesis.

An integrated concept that combines the three innovations of this thesis, local water supply, local energy supply and floating urbanisation will be presented. The potential of floating urbanisation to reduce vulnerability is discussed. A number of follow up projects emerged from research activities in the Transition SUW projects. It is discussed how these findings were translated to practice.

6.1.1 Background

The urban population is expected to double from 2 billion to 4 billion in the next 30 to 35 years. For the first time in history, the proportion of people living in cities is equal to the rural population on a global scale (UNFPA, 2007). More than 200,000 people move to cities every day (UNFPA, 2007). Urbanisation predominantly takes place in coastal and river plains that are exposed to flood risks. In 2003, 23% of the world population lived within 100 kilometres of the coast (Small and Nichols, 2003). In 2030, this percentage is expected to increase up to 50% (Adger et al., 2005). Climate change and sea level rise, described in chapter 2, will further increase the vulnerability of delta areas. Flood damage increased significantly over the past decades and will be increasing further due to climate change and urbanisation (Kron, 2005). In literature, various examples have been described to improve the climate robustness of cities with regard to droughts, heat stress and flooding. For instance, Van de Ven et al. (2008) have identified 150 measures that reduce the vulnerability of urban areas. With regard to flood proof urbanisation, these measures include wetproofing and dryproofing of buildings and infrastructure, building on mounds, building on stilts, constructing a higher freeboard between road level and floor level, flexible and removable constructions, amphibious housing and floating urbanisation.

6.1.2 Living on water, a niche market

The publication *Mooring Site Amsterdam* (Kloos and De Korte, 2007) describes the history of living on water in the Netherlands, in particular in Amsterdam. Paintings and laws in the municipal archives show that already in the 17th century there were houseboats. In the following centuries houseboats remained an important element of the water city. Housing shortage after the two world wars increased the number of houseboats to an estimated number of 10,000 at the end of the 20th century. Authorities have always struggled to regulate these ‘pioneers’ on the water. Even today, it remains unclear which spatial planning regulation apply to houseboats, notwithstanding all the policy documents that have been produced to provide more clarity (Kloos and De Korte, 2007).

Over the last decade, there has been a new development: the rising popularity of the floating house. Contrary to the houseboat which is usually a boat that is reconstructed as a place to live in, this is an ordinary house that is constructed on a floating foundation. This housing type is included and regulated in the spatial development plans of the municipality. The following parts of this chapter, describes how floating houses are entering the mainstream construction industry and mainstream urbanisation practice in the Netherlands.

6.2 Mainstreaming of floating urbanisation

This section describes policy changes, financial aspects and legislation, technical development, planning and design, the development of a commercial market, current obstacles, a knowledge agenda and demonstration projects.

6.2.1 National policy

In the Netherlands, there has been a change in perception on water management. Van der Brugge et al. (2005) describe how over the past decades, water management approach has changed from a technical approach to a more integrative approach. River flooding in the mid 90’s and pluvial flooding at the end of 90’s led to the establishment of a new government policy, ‘dealing differently with water’ (Tielrooij, 2000). Water retention increased in importance and there was a shift in approach from ‘fighting the water’ to ‘living with water’. The research program *Living with Water*, of which this thesis is part, is a direct result of this new approach. The societal priority to create more storage capacity led to large projects. Examples are the Room for the Rivers project and the National Water Agreement. This agreement presents ambitious targets for water storage: 425 million m³ of additional water storage in the period to 2050 (NBW, 2003). According to the agreement an area of 690 km² should be made available for water storage. To give an indication, the largest lake in the Netherlands, the IJsselmeer has a surface area of 1100 km². Due to scarcity of space, high prices of land, and competing land use functions, these targets will be hard to realise. In the densely populated Dutch delta, floating urbanisation is proposed as a viable way to realise water retention objectives while obtaining economic benefits from urban development.

Floating urbanisation is encouraged by the national government. The Ministry of Spatial Planning has designated a 15 areas for innovative housing experiments (VROM, 2005), the so called EMAB locations. In these areas, constructing houses in the floodplain is allowed if innovative building methods are applied. Furthermore, the project should increase the spatial quality of the area and additional space for water should be integrated in the project. At the first National Congress on Floating Houses in 2008, the minister of Spatial Planning and Housing proclaimed that there should be more space for living on water. In the Strategic Knowledge

Agenda Water and Mobility of the Ministry of Transportation, Public Works and Water Management (Ministerie van Verkeer en Waterstaat, 2008a) floating urbanisation is mentioned as one of the key areas for further knowledge development. In December 2008, the National Water plan designated 1100 ha of national water in the IJmeer/Markermeer for water based urban development by the national government (Ministerie van Verkeer en Waterstaat, 2008b). This area will be handed over to the municipalities of Amsterdam, Almere and Lelystad. The availability of space for water based urbanisation will be a driver to develop plans for floating urbanisation.



Figure 6.1 Floating houses in Leidsche Rijn, Utrecht (source: Wenneke Lindemans)

6.2.2 Financial aspects and legislation

There has been a debate on the juridical and financial status of floating houses. Depending on this status they are regarded as boats or houses. Vice-minister Remkes proclaimed in 2000 that floating houses are regulated by land based construction legislation and housing legislation. Also the Council of State is clear about the juridical status. Based on jurisprudence, floating houses have the juridical status of a house if: 'there is an intention to stay on a certain location and the construction is connected to the underground with a mooring construction' (Vermande, 2009, translation RdG).

The juridical status of the house has consequences for mortgages, insurance and building permits. Currently, there are commercial banks and mortgage firms that sell mortgages and insurances for floating houses in the Netherlands. This has probably contributed to market demand and trust among potential house buyers. Floating houses require an ordinary building

permit and should fulfil standards in the construction legislation. The consultancy firm PRC in the Netherlands has started to interpret the construction legislation specifically for floating houses into a new guideline for developers and constructors (Vermande, 2009). This guideline includes technical topics such as: buoyancy, stability, wave movement, freeboard, tilting, safety for collision with ships, fire safety and emergency exits. The Steering Group Experimental Housing has given an advice to the minister of spatial planning to strive for complete juridical equality between floating houses (SEV, 2008). The steering group also advises to develop technical guidelines and standards to further contribute to mainstreaming of floating constructions into the construction industry. In Canada, such guidelines already have been developed. For instance the Office of Housing and Construction Standards of British Columbia provides guidelines⁶ on technical requirements, utilities, fire protection and maintenance. These guidelines are used by constructors to build floating houses and by authorities to approve development plans. Recently, the Netherlands Normalisation Institute (NEN) has started to develop standards for the floating housing industry.

6.2.3 Technical developments

In the Netherlands, most floating houses are constructed on a hollow concrete foundation. The oldest known floating house in the Netherlands that still exists was constructed in 1922 on such a foundation (Spruyt Arkenbouw, 2006). This system is relatively cheap and technically robust. Concrete segments can be connected to realise large platforms. The largest building in the Netherlands that was built on this type of platform is a prison in Zaandam. The floating foundation is 100 meters long and 22 meter wide. Disadvantages of this system are the required depth which is usually about 1.5 meters for a single house. The surface water in Dutch polders is generally shallow, about 1 to 1.5 meters. Therefore, the application remains limited to regional surface waters, lakes and canals.

In 1999, Construction Group Ooms imported a Canadian system to the Dutch market. This system is based on a core of polystyrene foam and a concrete shell. The polystyrene decreases the density of the floating construction which provides higher buoyancy. Advantages of this system are a lower required depth of the surface water. In addition the system is unsinkable and enables the construction of larger platforms. The system is more suitable for shallow surface water. A depth of 1.5 meter can be sufficient. However, the material costs are higher than the concrete system.

Another polystyrene concrete system was developed by contractor Dura Vermeer and polystyrene manufacturer Unidek. This system (Flexbase) is based on polystyrene blocks on which concrete is poured to form the ground floor of a floating building. This system was applied as a pilot in a floating greenhouse in Naaldwijk in 2005. The system is constructed on the water. There is no limitation resulting from a construction dock. The system therefore offers more degrees of freedom with regard to form and size.

Next to floating houses, the floating structure technology can be applied in amphibious housing. In particular in floodplains and emergency water retention basins, this construction method can be applied. During normal operation the house is located on a concrete foundation structure. During flooding however, the construction will start to float because of the floating foundation floor and the mooring construction that keeps the house on the location. An example

⁶ http://www.housing.gov.bc.ca/building/floatho1.html#_1_3, accessed 17 September 2009

of amphibious housing project in the Netherlands is Maasbommel where 32 amphibious houses have been constructed.

Weak soils are a large potential field of application of floating structure technology and lightweight constructions. In the western part of Netherlands, constructions are placed on pile foundations due to the low carrying capacity of the clay and peat soils. In addition, building site preparation by integral or partial sand fill is generally applied to make lowland areas suitable for urbanisation. This results in continuous land subsidence which causes high costs for maintenance of the public space and infrastructure. Lightweight constructions and infrastructure can make pile foundations and traditional building site preparation in delta areas obsolete. Research institute Deltares has started to do research on subsidence free cities (Van de Ven, 2009).

Besides floating housing, infrastructure on the water has been developed. In the Netherlands, the first step to develop floating infrastructure was made in 1999 when the Ministry of Transport, Public Works and Water management started to develop a pilot floating road in the project 'Roads to the Future.' The objective of the floating road is to deal with traffic congestion in a flexible way in areas with poor soil conditions or fluctuating water levels. Another objective is to contribute to the multifunctional use of space (Ministerie van Verkeer en Waterstaat, 2004). The design and realisation was done by a consortium of Bayards Aluminium Construction, DHV, TNO and XX architects. The construction consists of aluminium segments of 3.5 meters long and 8 meters wide that are filled with polystyrene to make the construction unsinkable. The prototype floating road was realised in 2003 near Den Bosch in the Netherlands. The road is suitable for cars with a weight of 2000 kg and a velocity of 80 km/h (TNO, 2003). In particular for temporary connections during reconstruction or renovation of tunnels and bridges, the floating road is an attractive solution (Ministerie van Verkeer en Waterstaat, 2004). It is also a promising technology for application in floating cities.



Figure 6.2 Floating road near Den Bosch (Ministerie van Verkeer en Waterstaat, 2004)

On a small scale floating gardens are constructed in the Netherlands. Inventor Robert Jasper Grootveld started to build them already in the 1960's. The gardens are based on a system of polystyrene blocks that are tied together with fishing nets. On top of these blocks a layer of soil is placed that enables the development of vegetation, including grass, shrubs and trees. This technology enables the development of soft surfaces such as parks and gardens in floating cities.

Recent research investigates modular floating technology (Rijcken, 2003) and the possibilities of combinations of High Performance Concrete and polystyrene (Kuijper, 2006). Also high strength fibres are proposed in the floating constructions industry from the field of maritime engineering and shipyards. Although more expensive, these systems are lighter and stronger than the foundations that are currently on the market. This development potentially enables the construction of large scale projects on the water including infrastructure, access with motorised transport and public space.

6.2.4 Planning and design

There is a scale increase of planning and design from individual houses to floating neighbourhoods and floating cities. In 1999, the concept of New Arcania was presented by the Dutch engineering firm Advin as their submission in the design contest 'water landscape of the future'. The concept consists of a vision on multifunctional use of space by floating urbanisation in a wetland area.

Planning and design of floating urbanisation is becoming more mainstream. Large municipalities in the Netherlands, such as Almere, Amsterdam and Rotterdam have included floating urbanisation in their spatial development plans (Czapiewska, 2008). Considerations to include floating urbanisation are the lack of space, the objective to stimulate innovation and the ambition to create more water storage capacity.

The idea of constructing floating cities on the sea was coined by Prof. Frits Schoute (2000) of Delft University of Technology in his retirement lecture. He introduced the philosophy of 'ecoboats' floating urbanisation units that are independent of fossil fuels. According to Schoute, climate change and the lack of space, energy and water in megacities will eventually lead to sustainable urbanisation on the sea.

Today, The Seasteading Institute in San Francisco is developing plans to build floating cities on the ocean. The first prototype should be realised in 2010. The mission is to 'further the establishment and growth of permanent, autonomous ocean communities, enabling innovation with new political and social systems.' (TSI, 2009).

Inspired by the idea of prof. Schoute, the author of this thesis, with a team of architecture and civil engineering students (DeltaSync) developed a strategic plan and design for a floating city in the IJmeer area between Amsterdam and Almere (De Graaf et al., 2006). This plan was first prize winner in the international Deltacompetition of engineering firm Royal Haskoning. The plan had the following benefits.

- A living space for thousands, reducing the need for conventional land reclamation
- A positive influence on regional ecology by large scale wetland development
- Self supporting urban development, using the water system as source of energy and local water supply
- An iconic project, further increasing tourist appeal of the IJmeer
- A demonstration project for larger floating cities

- Testing ground or accelerator for floating technology, resulting in knowledge and products that can be exported

The vision of the floating city was received positively by many organisations. It is a water management innovation that connects to many urgent regional problems such as: poor water quality and ecology of the IJmeer, mobility problems in the Almere- Amsterdam area, housing shortage, and the objective to become a knowledge based economy. The risks to start the project can be relatively small because the development can start with one building and then gradually expand while new technologies and knowledge are included in the process and the concept is gradually improved. National sustainability initiative Urgenda adopted the floating city as an icon project. TU Delft used the idea in a national campaign on high schools to attract more students.

6.2.5 Development of a commercial market

Next to 10,000 houseboats in the Netherlands, the number of floating houses remains limited. Figure 6.3 shows that until 2008, about a number of 200 floating and amphibious houses have been realised. The first project (1992) was the development of 80 floating houses in Marina Olderhuuske. Most floating houses are recreational, for instance in Maasbommel (45) and Marina Olderhuuske (80). Most of the projects are small scale and situated along the edges of rivers and lakes. In the new Amsterdam development IJburg, another 185 floating houses are realised. A large scale new project is Het Nieuwe Water in Naaldwijk with 600 floating houses.

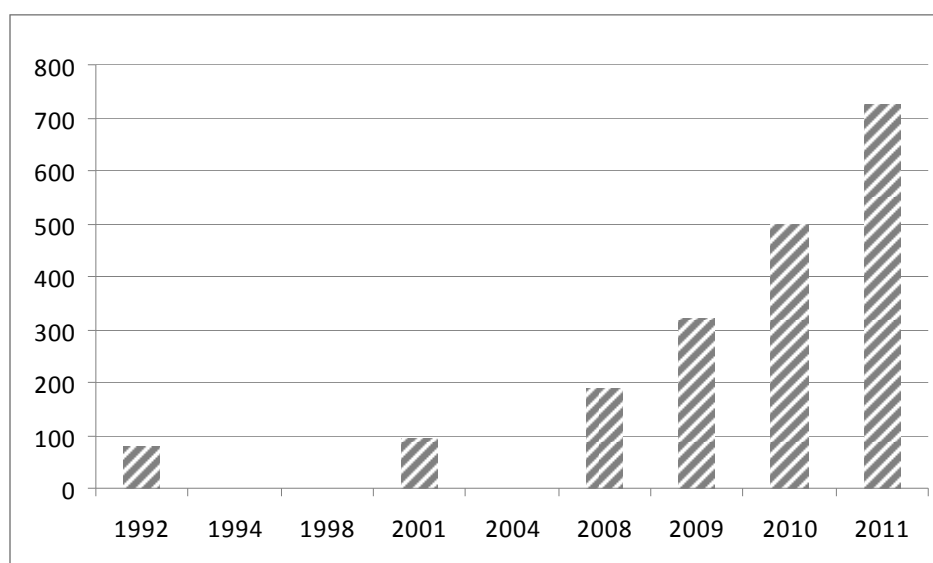


Figure 6.3 New floating houses in the Netherlands including projections for 2009 to 2011 (Czapiewka, 2008; SEV, 2008)

Generally, there has been much attention from buyers for the projects that have been realised. For the first 37 water plots in Amsterdam IJburg in 2006, 381 subscriptions were received. Prizes for the plots ranged from € 116.000 tot € 142.000 (SEV, 2008). However some projects also failed, for instance due to long walking distances to parking space (Schuwer, 2007). The lack of parking space and the lack of public space are still obstacles for increase of scale. The total potential market for floating houses is estimated at 360,000 houses (Heijmans, 2006). TU Delft-OTB studied the profile of potential buyers of floating houses with a questionnaire. There were

112 respondents. Potential buyers generally have a high education, a high income, are predominantly between 25 and 50 years, and spend their free time on water recreation. A floating house is attractive for them because of the space and view on the surroundings, the living environment near the water, and because the house is designed and constructed according to their wishes (SEV, 2008). Residents in the Netherlands value a living environment next to the water. Although there are no specific numbers for floating urbanisation, the survey of Bervaes and Vreke (2004) shows that houses next to water are 8 to 16% more expensive compared to ordinary houses.

It can be concluded that floating houses is still a small luxury market. However, there is a strong market demand that could contribute to the diffusion of this mode of living to the middle and lower end of the market. This is driven by a trend toward larger scale projects, in which these segments of the housing market should also have a place. Figure 6.3 shows the steady increase of the number of floating houses in the Netherlands. Besides consumers, also entrepreneurs have discovered the market. In the Netherlands, 15 architecture firms have already designed floating houses. Four of them are specialised in this field. The number of technology start-ups is increasing. An example is DeltaSync that was founded in 2007 by the students that had won the Deltacompetition. Moreover large established construction companies are starting to focus on floating urbanisation. (Czapiewska, 2008).

6.2.6 Obstacles to further development of floating urbanisation

Despite rapid developments in the field of floating urbanisation, there are still concerns that it will remain a niche market. Many authors studies obstacles for implementation of floating houses (Fit, 2006; Schuwer, 2007; SEV, 2008; Czapiewka, 2008). These obstacles can be summarised as follows:

- Knowledge and skills
 - Lack of technical knowledge among contractors and developers
 - Lack of experience with floating houses among municipalities and waterboards
 - Lack of public space and parking space
- Rules and legislation
 - Lack of technical guidelines, standards and certification
 - Uncertainty about interpretation of juridical status
- Building process
 - Complexity of development processes
 - Conflicting interests between water management and spatial planning
- Exploitation and economy
 - Lack of trust in the development of the market
 - Investment costs
 - No experience in selling water plots
- Planning and design
 - Lack of space to develop projects
 - Accessibility for fire-fighters
- Technology
 - Problems with connection to utilities
- Ecology
 - Water quality impacts
- Fear of unknown risks

Most of these obstacles are not technical. Some of them are related to lack of knowledge, skills and experience with floating urbanisation. There seems to be a lack of receptivity among stakeholders. Chapter 9 and 10 will discuss this topic in detail. The lacking receptivity is unsurprising given the fact that floating urbanisation is still a niche market. In particular, local government officials who are responsible for issuing building permits are known to be reluctant to facilitate floating urbanisation. Local waterboard employees have difficulty in estimating the water quality impacts of floating urbanisation, although the potential of this innovation to create more water storage is valued by them.

Other obstacles are related to rules, legislation and planning. The lack of technical guidelines and standards makes it difficult for building contractors to construct floating houses. The interpretation of the juridical status is a perceived obstacle. Although the legislation is rather clear, there is still a lack of knowledge among stakeholders with regard to the juridical status. The complexity of the development process is mentioned as an obstacle for floating urbanisation. However, one could argue that building projects in general are complex. This is not only the case for floating housing projects.

Financial obstacles to further development of the market remain. Although many banks sell mortgages that are specifically made for floating houses, not all investors are already convinced that floating urbanisation will develop in a full grown market. This may limit the possibility to finance projects and may therefore be an obstacle for the further development of floating urbanisation. Investment costs, in particular with regard to connecting floating houses to utilities and infrastructure, remain a barrier. Construction costs of floating houses are comparable to land based houses, but connecting them to infrastructure and utilities make them more expensive. Waterboards and municipalities have no experience in the commercial exploitation of surface water for economic development, for instance by selling water plots.

The lack of public space and parking space is a problem in many realised projects. Future planning and design of floating urbanisation projects should therefore better incorporate these facilities. This is also the case for the accessibility for fire-fighters.

More research is needed to quantify the impact of large scale floating urbanisation on water quality, in particular with regard to the entry of sunlight to the watersystem. At this moment, the water quality effects of large scale projects are still unknown.

The experience there currently is with projects that have been realised, should be used optimally. Knowledge transfer of these projects to other municipalities, waterboards and contractors is needed. A learning process to fulfil other roles in the urban development process is required for floating urbanisation to go through the take off stage. A good example is the commercial exploitation of water plots by waterboards. The start of demonstration projects to build experience with this form of urbanisation and different roles could contribute to further mainstreaming.

6.2.7 Knowledge agenda

After winning the international Deltacompetition by TU Delft students, the TU Delft became increasingly interested in using the Floating City to do relevant, interdisciplinary research. The Dean of the Faculty of Civil Engineering launched an initiative to develop a knowledge agenda for the further development of floating urbanisation. A workshop was organised in March 2007 that was joined by professors from several faculties. The result was a list of main research topics that are to be studied in more detail to enable the development of floating cities. Several themes received priority by the workshop participants.

Technical themes included the development of new building materials, recycling and floating foundations. Other topics to be further investigated were: sustainable water and energy supply and accessibility of floating cities. In particular the connection to the mainland was considered important. Water quality and ecological impacts remain an area that needs to be further explored and investigated. This can be done by small scale demonstration projects including thorough water quality and ecological monitoring.

Social themes included the social acceptability of living on water, consequences for urban design, operation and maintenance, health risks and public private partnerships. The presence of public space in floating cities was regarded a key condition for realisation. In addition ecological aspects and water quality effects of floating urbanisation have to be studied in more detail, in particular in relation to European legislation. The potential contribution of floating urbanisation to the objectives of sustainable development and adapting to climate change should be investigated in more detail. Economic themes of floating urbanisation are mainly the exploitation of floating houses and the formation of public-private partnerships for floating cities. The results of this workshop were used to write a research plan for an inter faculty research group on floating cities at Delft University of Technology. This plan was finished in August 2008 and is now used to raise funding to start a research group on floating cities.

6.3 Floating Utility Units, the step to floating cities

Currently, the realised projects are still small and located along the embankments of rivers, lakes and canals. One of the reasons is that there is no integrated infrastructure that enables urbanisation on the water. To address the problems that floating projects are currently experiencing with regard to connecting to energy and water infrastructure, the Steering Group of Housing Experiments (SEV) started a project to develop Floating Utility Units. These units should provide access to a floating district and at the same time provide space for decentralised concepts of water and energy supply. As such, the units are a combination of the three technologies that are described in this thesis: local water supply (chapter 4), local energy supply (chapter 5), and floating constructions (chapter 6). Figure 6.4 shows that this unit can also be integrated with floating public space and parking space for residents.

- 1) Flexible connections are used to optimally enable the placement and replacement of houses.
- 2) Cables and pipes are integrated in the floating construction for protection and to prevent freezing. These floating constructions are also used for accessibility of the floating district.
- 3) Permeable pavement is applied to purify runoff before discharging it to receiving waterways. Also biofilters (10) are used to minimise runoff impacts on ecological systems.
- 4) Local wastewater treatment is applied based on separate collection of urine, and faeces. No pressurised connection to the main sewer system is needed. A local MBR installation can be used to achieve water quality standards.
- 5) A local water purification system, as described in chapter 4, can be integrated in the floating construction. Depending on the water quality of the source, nanofiltration can be applied to produce high quality drinking water.
- 6) The Floating Utility Units use the urban water system as a solar collector (chapter 5). Heatpumps are used to extract heat from the water system that is used to heat floating houses. In rivers, ports and lakes, the same system is used for cooling during summer.
- 7) Clean drinking water can be stored under water after it is locally produced. This provides an emergency storage and reduces peak demands on the production units.

- 8) Small scale wind turbines are used to contribute to a self supporting energy supply. A small wind turbine may fulfil 10-15% of the energy demand of a house.
- 9) Photovoltaic cells are used to make the floating district more self supporting. This is combined with parking spaces to enable multi functional use of space.

A Floating Utility Unit would make a scale increase possible for floating urbanisation. Although it does not make an area entirely self supporting, no external gas and water supply is required. Therefore it is an alternative for large scale networks of water and energy supply. At present, DeltaSync and SEV are forming a consortium to build the first unit as a pilot project. This would be a learning opportunity for new modes of urbanisation and self supporting urban development. The unit enables a more flexible and adaptable way of living. Houses can be sold and purchased separately. Residents can move with their house to another location. Alternatively, residents may stay on the same location, sell their house, and buy a new house for their water plot (Rijcken, 2006).

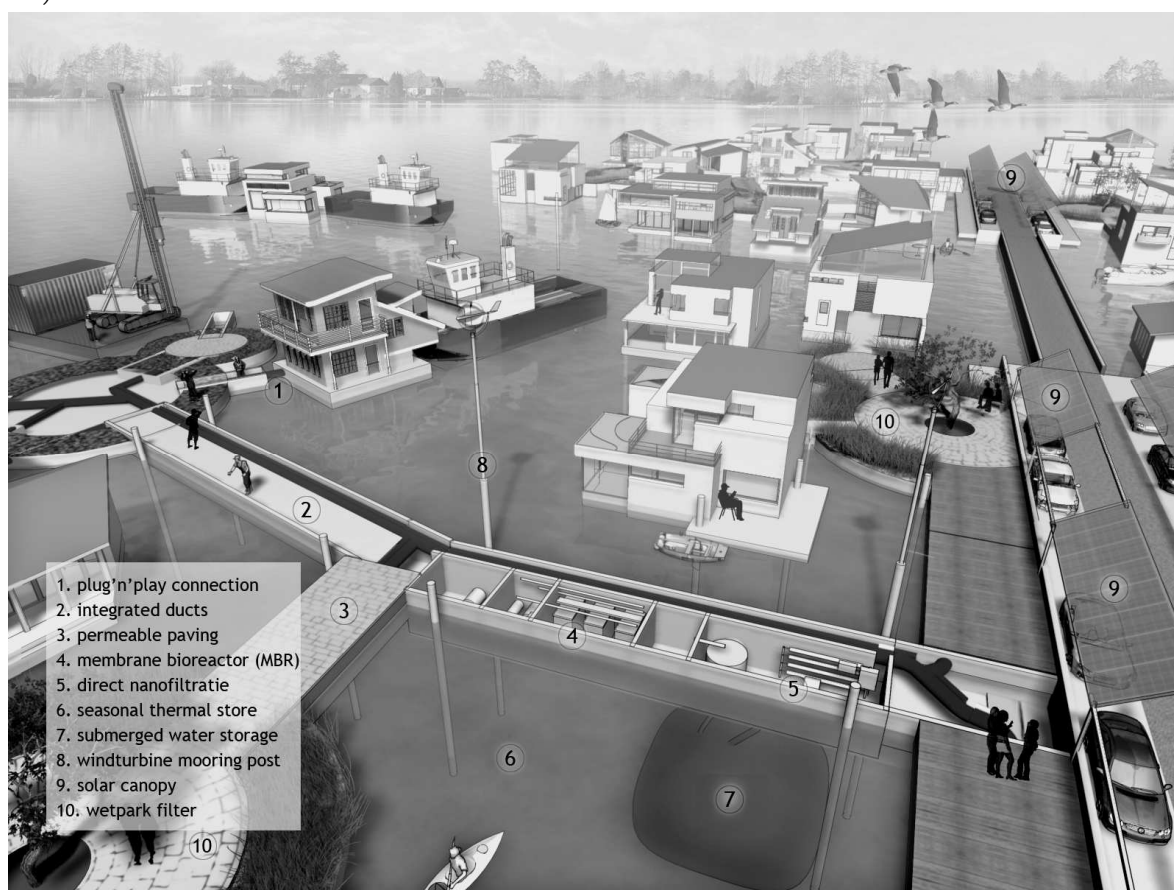


Figure 6.4 Impression of a Floating Utility Unit to enable urbanisation on a larger scale (Source: DeltaSync)

6.4 Analysis

6.4.1 Technical feasibility

An increasing number of floating urbanisation projects in the Netherlands and abroad demonstrate the technical feasibility. However, most of these projects are still small scale and located along the edges of lakes and rivers. These small scale settlements are still completely dependent on land based infrastructure. Technical obstacles are related to the connection with utilities, accessibility from the mainland, and creating public space on the water. Water quality and ecological impacts of floating urbanisation should be evaluated in more detail. The concept of the Floating Utility Unit that was demonstrated in this chapter could contribute to the realisation of larger projects and serve as a medium to urbanise on the water, rather than along the edges. In addition it provides a way to realise more self-supporting floating urban districts. The societal objective to realise more water retention capacity in order to adapt to climate change could become economically feasible by the revenues of urbanisation on water. Delta lowland areas all over the world face problems similar to the Netherlands. They are confronted with urbanisation, climate change and scarcity of space. In these areas, floating and amphibious urbanisation can provide an opportunity for multifunctional use of space. Although floating urbanisation is technically feasible there are also risks to this type of development. One risk is the fact that open space on the water is lost due to urbanisation. This is a potential problem in the Netherlands where open space is scarce and valuable. This risk can be handled by only allowing floating urbanisation near existing urban areas in spatial zoning plans.

Development of the market can possibly lead to the introduction of low quality floating constructions. The Netherlands Normalisation Institute (NEN) have recently started the standardisation of floating and amphibious constructions to contribute to developing the floating housing market further while assuring the quality of floating construction. Ecological impacts and water quality impacts of large scale floating urbanisation are still unknown. These impacts should be carefully monitored while floating urbanisation starts small scale. This will contribute to better knowledge with regard to water quality. The impacts should also remain limited by applying an incremental approach of urban development. Moreover, the construction of floating cities should be combined with the development of wetland areas to increase the ecological potential of delta areas. Although floating urbanisation is suitable to incorporate local concepts of water supply and energy supply, it is also possible to connect to the main infrastructure. In that case, floating cities would just be an additional pressure on nature rather than solution that improves the capacity of cities to become self supporting. This can be considered a risk. A possible way to prevent this is to impose regulation and standards to large scale urbanisation on the water.

6.4.2 Vulnerability

Floating urbanisation has the potential to contribute to reduce vulnerability of delta areas. During floods, floating constructions increase the coping capacity of an urban area. No damage to the construction will occur because floating houses will adapt to the rising water level. In addition, they may serve as emergency shelter during flooding. Because floating houses can be relocated, they are also flexible and reversible, which is a benefit to deal with uncertain future developments such as climate change. This contributes to strengthening of adaptive capacity. Floating constructions are in particular interesting for new urban areas. The potential of floating urbanisation to reduce vulnerability of existing urban areas remains limited. It is not feasible to

change current urban areas into floating urban areas. The majority of future urban areas are already there. For these kinds of areas, other solutions are necessary to reduce flood vulnerability.

6.4.3 Translation to practice

Floating urbanisation is entering the mainstream construction industry and is increasingly included in urban development plans. Drivers that contribute to the increasing attention of policy makers and planners for this concept include: climate change, sustainability and rapid global urbanisation in delta lowland areas. There is a strong market demand from consumer. However, at this moment, floating urbanisation is still a small luxury consumer niche market.

Although financial and legal obstacles remain, land based construction regulations and financing arrangements are increasingly applied to floating projects. Floating urbanisation is increasingly included in official regulation. Technical developments, such as high performance floating foundations and utility units enable development of large scale water based urbanisation. Planning and design for building on water are increasing in scale.

An obstacle is the lack of receptivity of government employees that are responsible for giving permits. There is a lack of knowledge on how to judge floating urbanisation plans in the authorisation process. In addition, most building contractors have limited or no experience with floating urbanisation. This obstacle could be addressed by capacity building among stakeholders, for instance with demonstration projects that are tied to research and training programs. The knowledge agenda that was outlined in this chapter could be further developed in these programs. In addition, these programs are required for stakeholders to develop experience with fulfilling new roles in the urban development process, such as commercial exploitation of water plots by waterboards.

One of the Transitions SUW case study cities, the city of Rotterdam, has adopted floating urbanisation as an opportunity for climate adaptation and innovation. Following an invited presentation at the Shanghai World Expo Committee in July 2007, the Rotterdam project partners in the Transitions SUW project were positive about realizing a floating icon project in the Port of Rotterdam. They started a lobby within the municipality to develop critical mass for this idea. The concept was a valuable potential contribution to ongoing programs such as Rotterdam Climate Initiative, Waterplan 2 and the Knowledge for Climate research program.

In March 2008, a meeting was planned with the Transitions SUW project and the executive of the Municipal Works Department of the municipality. Following this meeting DeltaSync was commissioned by the municipality to study potential locations for a floating icon project and develop sketch designs. Three port areas came out as the best potential location. The study was finished in October 2008. The municipal board decided positively about the project. On 28 October 2008, they commissioned the municipal department to start working to develop a business case and project specification. The project should be finished in May 2010 as the Rotterdam counterpart of the Shanghai World Expo. Also the other case study cities in the Transitions SUW project showed interest in floating urbanisation. Heerhugowaard will apply the concept on a small scale in De Draai. Also Amsterdam is interested; a presentation was given to the project team of the new urban development IJburg2.

6.5 Conclusion

This chapter described how floating urbanisation is developing from a niche market of houseboats to a more developed industry that works on large scale urbanisation plans. This shift is facilitated by changes in government policy, technical developments, standardisation, and the development of a commercial market. The importance of these factors for application of new technologies is tested in chapter 10.

Influential stakeholders such as the municipality of Rotterdam, sustainability platform Urgenda and Delft University of Technology have embraced the concept of floating cities. The main technical obstacles are decentralised water and energy supply of floating cities, and the accessibility of floating cities, in particular with regard to parking space and connection to the mainland. Lacking receptivity among stakeholders remains a barrier for mainstreaming of floating urbanisation. Receptivity is further studied in chapters 9 and 10.

Risks of floating urbanisation include the loss of open space, the technical quality of floating constructions, and unknown water quality impacts. A potential way to address this problem is capacity building through well-designed, well build, and well maintained demonstration projects that are carefully monitored and evaluated. This will produce experiential knowledge among contractors, local government employees, utilities and residents.

PART 2: MAINSTREAMING OF URBAN WATER MANAGEMENT INNOVATIONS

7 Mainstreaming of urban water management innovations, contributions from social theory

7.1 Introduction

Part 1 of this thesis described how innovations in urban water management can contribute to reduce the vulnerability of cities. Next to showing the technical feasibility, observations were made from the perspective of a reflective practitioner on factors that contribute to the application and mainstreaming of innovations. These observations explain why in specific case studies, certain innovations were applied or were rejected. This offers a perspective from practice in the mechanisms of technology adoption. In the case studies, a collaborative relation with practitioners was established. Therefore, the perspective in part 1 includes the knowledge and experience of practitioners that would not have been used if another method was applied. However, there are also two problems with this case study approach, as was described in chapter 1. Specific observations in case studies are not necessarily valid in other situations. Moreover, the observations of a reflective practitioner are personal and therefore subjective. Part 2 of this thesis aims to complement the case study specific view 'from the inside' with a perspective 'from the outside'. For this purpose, multiple methods are applied. This chapter reflects on theory and findings from literature to identify two key conditions that determine mainstreaming of innovations. Chapter 8 presents the results of an in-depth interview research in Rotterdam. Chapter 9 and 10 presents the results of a national survey among urban water managers. The results of part 1 and part 2 are brought together in the concluding chapter of this thesis to present general conclusions and recommendations.

7.1.1 Background

In recent years, researchers have become interested in the ongoing transformation of urban water management. Changes in the urban water management approach can be classified as paradigm shifts, transitions, regime shifts or transformations (Van der Brugge et al., 2005; Brown and Clarke, 2007; SWITCH, 2007). The effects of climate change and developments such as urbanisation, the European Water Framework Directive, and societal concerns about the sustainability of urban water management force the sector to adapt.

New concepts in urban water management reflect approaches in which the connection with urban planning and social amenity is highlighted. Most approaches stress the necessity of an integrated system approach that includes the total urban water cycle. An important element in most approaches is the use of an integrated, cross-sectoral, multidisciplinary institutional framework (e.g. Butler and Parkinson 1997; Niemczynowicz, 1999; Geldof and Stahre, 2006). Some authors consider the urban water system as a complex adaptive system (Geldof and Stahre, 2006) or socio-technical system (Brown and Clarke, 2007) rather than a technical system.

Also in Dutch water management, a structural change has taken place from a technological approach towards an integrated and interactive approach (Van der Brugge et al., 2005). The Dutch urban water infrastructure predominantly consists of centralised end-of-pipe technologies. This system was developed and implemented in the nineteenth and the first part of the twentieth century.

Despite new approaches in urban water management, water infrastructure in the Western world has a rather uniform character: capital intensive and centralised. This is in particular the case for water supply and sanitation. Decision making is characterised by a rational, cost/benefit

driven approach (Starkl et al., 2009). The management culture is hierarchical and dominated by expert knowledge (Brown, 2005). Chapter 9 reports on a Dutch national survey on stakeholder perceptions in urban water management. Results from this survey show that the majority of respondents considered optimisation of the current urban water management system sufficient to fulfil national and European water management objectives.

The international literature describes many local scale urban water management technologies that are well documented and reliable. Yet, implementation of these technologies remains limited to pilot projects and incremental improvement of the current centralised system. An example is the Dutch program for disconnection of paved surfaces from combined sewer systems. This program started in the late 80's to prevent mixing of runoff with wastewater in sewer systems to reduce combined sewer overflows. Another consideration was the improvement of wastewater treatment plant performance. The program is an incremental solution. It leaves the existing combined sewer system in place and improves the sewer performance. While the disconnection program is now generally applied, in 2005 the total disconnection rate of paved areas in the Netherlands was 4.3% (Rioned, 2009). This example illustrates that even for incremental innovations long timeframes are needed to change the current system.

Part 1 of this thesis demonstrated that a wide range of technical innovations are feasible. These technologies use the urban water system for new functions in order to decrease the vulnerability of urban areas; to reduce the parasitic behaviour of cities and make better use of local resources; to utilise a wide range of water resources instead of only one; and to reduce the environmental footprint of cities. However, urban water management innovations are often isolated showpieces that hardly contribute to the overall transformation of the urban water system (Brown, 2005; Hunt and Rogers, 2005). These innovations are hardly evaluated and improved. Neither does replication of demonstration projects take place on a large scale. Therefore, they remain isolated and fail to influence mainstream day-to day urban water management practice.

Table 7.1 demonstrates that organisations in urban water management have clear formal responsibilities. In the Netherlands, waterboards are responsible for flood control, water quality management, wastewater treatment and surface water management. Municipalities are responsible for the sewer system and stormwater management. Fragmentation of responsibilities leads to separate optimisation of parts of the system without taking into account total system performance (Wong, 2006a). The current technical infrastructure and institutional structure still reflect the social values that originate from the time when they were first constructed. The most important value is public health. An interesting question therefore is how urban water infrastructure could be transformed to include other socio economic and ecological values and functions that were summarised in chapter 1.

Institutional obstacles are often mentioned as the main explanation for poor implementation of urban water management innovations (Newman and Mouritz, 1996; Brown, 2005; Roy et al., 2008). Current urban water systems are technologically and institutionally locked in the conventional paradigm (Kotz and Hiessl, 2005). The same authors argue that the most important question is how to make a transition from the existing systems to more sustainable systems. Ashley et al. (2007a) state that: 'unfortunately existing governance, regulatory and institutional arrangements may constrain the ability of the sewerage undertakers to make the best and most sustainable choices.'

Table 7.1 Responsibilities of organisations and residents in Dutch urban water management

Stakeholder	Responsibility
European Union	- Enforcement of European legislation in urban water management such as the European Water Framework Directive
National government, Ministry of Transportation, Public Works and Water management	- Flood protection and water management of main river system - Supervision on implementation of European Water Framework Directive (EWFd) - Developing national water policy and legislation
Provinces	- Regulation of groundwater extractions - Supervision on waterboards - Drawing up regional water plans
Waterboards	- Flood control - Water quality management, wastewater treatment - Draining of polders and main canals
Municipalities	- Sewer system installation, operation and maintenance - Stormwater management in public space - Groundwater management in public space
Residents	- Collection of stormwater on private property - Groundwater management on private property
Drinking water company	- Production and distribution of drinking water - Operation and maintenance of the drinking water supply infrastructure

The institutional capacity to implement and maintain innovations is an important element for the transformation of urban water systems (Söderberg and Johansson, 2006; Wong, 2006a). Pahl-Wostl (2005) stated that the shared knowledge of professionals combined with expectations of stakeholders causes a status quo in the water system. According to her, the inertia in the technical system and the social rules and habits are obstacles to change. Brown and Farrelly (2009) conducted an extensive international literature review on socio-institutional obstacles that prevent urban water management from changing. They found 12 barrier types that were mainly related to insufficient capacity and commitment of urban water management stakeholders to change their way of working.

Brown and Keath (2008) propose social theory as an essential field of science that can assist in understanding and promoting mainstreaming of new urban water management technologies into mainstream professional practice. Therefore, this chapter draws on social theory and technical change theories to develop insight in mechanisms that influence the application and diffusion of innovative concepts in urban water management.

7.2 Large technical systems

Urban water systems can be regarded as Large technical Systems (LTS) (Kotz and Hiessl, 2005; Hegger et al., 2006). The functioning of these systems cannot be solely explained by the interaction and processes of the physical network. Other components such as immaterial artefacts, guiding principles for designers and the interests of stakeholders play an essential role (Hughes, 1987). These components are connected into a network structure to perform societal functions and acquire resources to maintain the functioning of the system. Therefore, it is more accurate to speak of a socio-technical system, rather than a technical system. As observed by Lienert et al. (2006) socio-technical systems tend to focus on continuous incremental improvement than rather radical restructuring. In most cases the sector is conservative (Malmqvist et al., 2006). Innovations that are not compatible with mainstream urban water management face difficulty to break through. Innovations in water management that require a new way of working, new skills and new knowledge will not easily be adopted even if they are technically and economically feasible.

Resources that are acquired by the urban water system are financial resources in the form of taxes, government subsidies, and user fees. Natural resources include water, building materials, and chemicals. Large technical systems are generally more competitive in acquiring resources than competing innovations.

The network of a LTS changes its structure continuously to adapt to changes, both inside and outside the water system. These changes are incremental rather than radical. Large technical systems acquire momentum (Hughes, 1987). Momentum includes concepts such as: vested interests, fixed assets, inertia, knowledge of the current system, technical trajectories and sunk costs. User expectations, institutions, social values have generally co-evolved with technical systems. Therefore, changing these systems is obstructed by technical, institutional and social barriers.

7.3 Multilevel perspective

The multilevel perspective (MLP) (Rip and Kemp, 1998) provides an analytical framework to study change processes within different layers of a large socio-technical system and interaction between these layers. They make a distinction between processes on macro level, meso level and micro level. The framework provides guidance in understanding under which conditions niche developments may break through to the mainstream regime of a large socio-technical system. Figure 7.1 illustrates the multilevel perspective. Geels (2002) argues that interacting processes on the three levels of scale should reinforce the overall change processes of the socio-technical regime to ultimately lead to a transition.

7.3.1 Framework

The macro level involves patterns of transformation of society that are characterised by long time scales such as dominant worldviews, macro economic developments, global political changes and large scale environmental processes. Change at this level takes place in decades and cannot be influenced by individuals.

At the meso level, there is a regime of technical networks and institutional structures. Regimes are dominant cluster of artefacts, institutions, rules and norms assembled and maintained to perform economic and social activities (Berkhout et al., 2003). Regimes are characterised by a dominant culture, structure and practice (Rotmans et al., 2001). They have

shared norms and shared common practice within a community of engineers, authorities, developers, consultants and manufacturers.

The concept of technological regime is related to Large Technical Systems and was proposed by Nelson and Winter (1982) to describe technical change dynamics. They found that technical change is patterned and develops along certain pathways and trajectories. This refers to rules that guide further technological development of a technology or technical system, and consequently create stability (Rip and Kemp, 1998). Guiding principles, for instance efficiency, and professional expectations of technological development, guide the design of technologies and may lead to the reformulation of rules (Van de Poel, 2000). These pathways help researchers and engineers to find research directions that lead to incremental change. However, it often leads to a lock in pattern that excludes alternative options. Mouritz (1996) stated that there will only be significant changes in urban water management if innovations are institutionalised in professional practice and supported by the socio-political context. Professional practice in the definition of Mouritz includes the institutions, bureaucracies and the culture within a group of professionals.

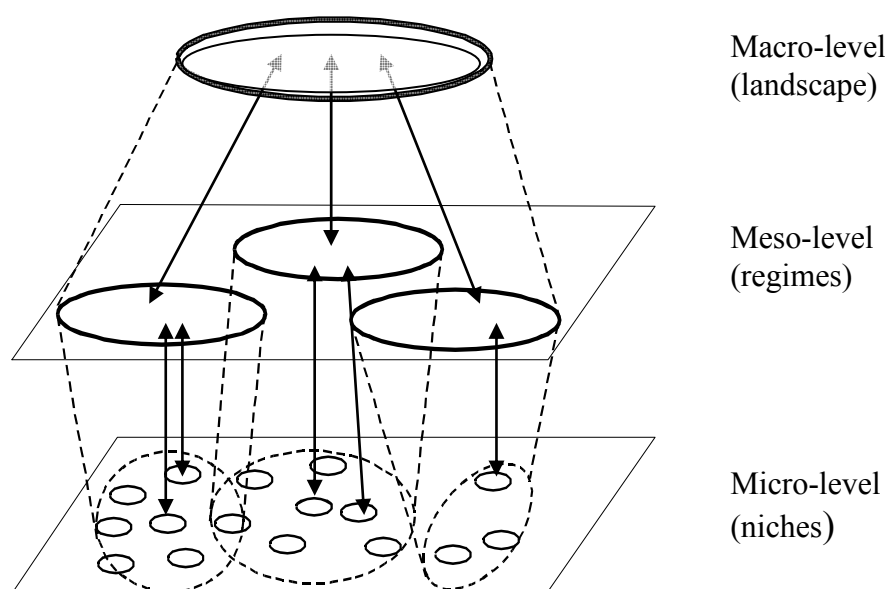


Figure 7.1 Interaction between different scale-levels (Geels and Kemp, 2000)

Because the technical regime cannot be regarded to be separate from the social context, Geels (2002) speaks about a socio-technical regime. Regime actors depend on the continuing functioning of the regime. In general, large technical systems will strive for incremental change that does not threaten the position of the actors that are part of the system. Only if a problem can no longer be temporarily solved by optimisation of the current system, the regime stakeholders will support radical change.

Due to stability and trajectories, changing large technical infrastructure systems, such as urban water infrastructure, is problematic. Brown and Keath (2008) compare the transitioning to sustainable urban water management to the turning of a super tanker. For water management the regime level has been further elaborated by Van der Brugge. Figure 7.2 describes the water management regime in the Netherlands. The figure shows the assembled nature of the regime. The technical system functions because of laws, norms and organisations and the other way around. Technical artefacts interact with the natural components of the water system. It seems that societal change programs in complex systems tend to focus on one or two components of

the regime rather than on integrated system dynamics. Because regime components are strongly interrelated and have a high complexity, changing one component has no effect, limited effects, or unpredicted effects. This may be a reason why the results of these interventions are often disappointing. Examples of interventions that address component of the regime are: technology push programs, awareness campaigns, mono functional interventions, new legislation or organisational reform.

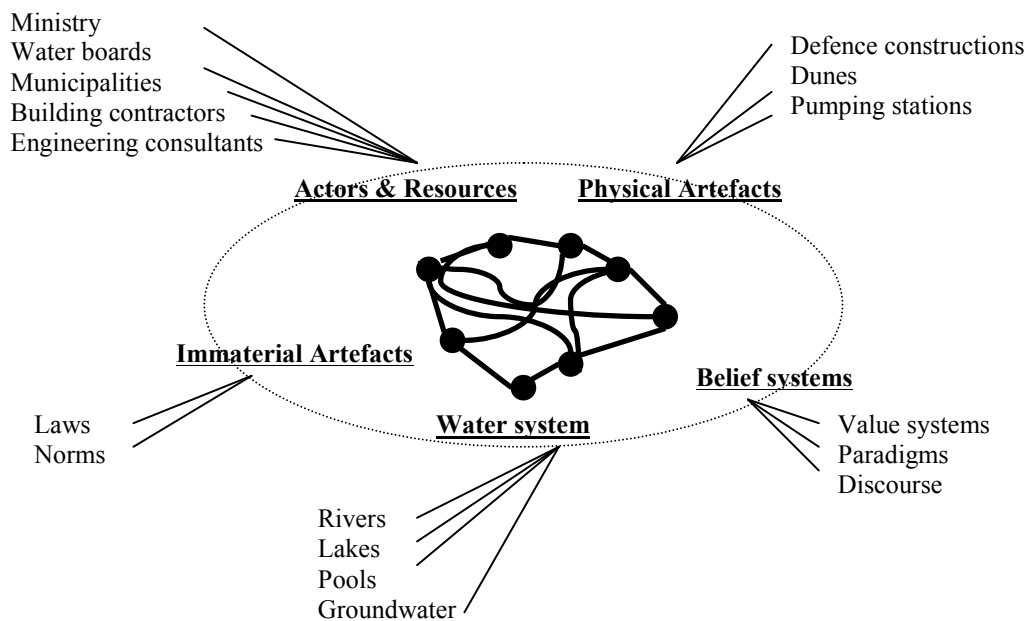


Figure 7.2 Schematisation of the water management regime in the Netherlands (Van der Brugge and De Graaf, 2006)

At the micro level, variations to and deviations from this regime take place, such as the development of innovative technologies, new methods of policy making and new social practices. Radical innovations that differ from the mainstream are protected in niches from selection mechanisms of mainstream practice. Niches offer a protective space in which innovation can further develop until they are strong enough to compete with the regime. Niches are small and unstable because stakeholders explore multiple trajectories of socio-technical change.

Niches provide space to build the social networks which support innovations, e.g. supply chains and user–producer relationships. These internal niches processes have been analyzed and described under the heading of strategic niche management (Kemp et al., 1998). Rip and Kemp (1998) state that the selection environment is actively modified to increase the survival chances of an innovation. Multilevel analyses of historic urban water management transitions (Van der Brugge et al., 2005, Geels, 2005; Geels; 2006; Brown and Clarke 2007) show that interaction between regime changes at the meso level, and processes on the micro level is a condition for transforming urban water systems.

7.3.2 Improving translation to regime

To successfully implement new concepts and new technologies, they must be embedded in the socio economic system, that is: user practices, perceptions, guidelines, legal frameworks and markets.

An important point of the multilevel perspective is that the success of a new technology is not only determined by processes within the niche, but also by developments at the level of the existing regime and the socio-technical landscape (Geels, 2005). Brown and Clarke (2007) found an interplay of micro level change agents and meso level enabling context in their research on the transition to water sensitive urban design in Melbourne. The results of Brown and Clarke can be regarded as an interesting example of niche-regime interaction.

Hegger et al. (2007) argue that technical demonstration niches often fail to influence mainstream practice. Niche actors develop radical technologies with limited potential for mainstreaming. The main reason for this strategic behaviour is the acquisition of resources and publicity. In addition, niche developers may only communicate positive impacts of their innovations to secure subsidies. There is no incentive for monitoring and learning. Consequently, there is hardly any improvement potential for these innovations. The prospects of competing with mainstream practice therefore remain limited.

Learning mechanisms to evaluate, improve and replicate niche projects are essential. Demonstration projects are often isolated showpieces, they lack coherence, are not monitored, and are not evaluated. Consequently they are not replicated and fail to influence mainstream practice. For this purpose there should be incentives and rewards for evaluation. These incentives should be built in the design of demonstration projects.

According to Smith (2007) niches are often constructed in opposition to the sustainability problems of the incumbent regime. In a certain way, they are designed to be incompatible to the mainstream regime and therefore necessarily face huge problems when it comes to mainstreaming.

Hegger et al. (2007) propose Conceptual Niche Management which is not focused on technical demonstration but more on transdisciplinary coalition building starting from a general objective of a more sustainable system. Similar to (Van de Poel, 2000) they propose an important role for new actors or outsiders.

7.4 Transition theory

Transition theory can be used to explain why and how urban water infrastructures might transform. It provides an analytical framework to understand the factors that influence the change process from our current urban water system to a future state that is fundamentally different.

7.4.1 Framework

Transitions are defined as: “long term continuous process (25-50 years) of societal change during which the structure of society, or a subsystem of society, fundamentally changes” (Rotmans, et al., 2001). A transition is the result of transformative rather than incremental change. Therefore, transition theory is a suitable framework to understand mainstreaming of technologies that are not compatible with the current centralised large scale urban water infrastructure.

A structural change is the result of interacting social and technical changes that operate simultaneously at different scales in technological, economic, ecological, socio-cultural and institutional domains. Transitions typically take a generation or more to develop.

Transition experiments are small scale demonstration projects aimed at sustainable system innovation and institutional change. Transition management scientists argue that experimenting and learning by doing is necessary to cope with complexity and uncertainty. By executing transition experiments, learning with new modes of urbanisation and water management takes place rather than optimizing existing infrastructure. The information and experience gained by these experiments provide knowledge and experience to society and are used to improve other experiments. Four phases during transitions are distinguished (Rotmans et al., 2001):

1. During the pre-development phase there is no change in mainstream practice.
2. During the take-off phase, the system begins to shift and innovations succeed in attracting external resources.
3. During the acceleration phase, structural changes in the regime take place as a result of accumulation of social, economic, cultural, ecological and institutional innovations that reinforce each other.
4. During the stabilisation phase the new system structures stabilise and the new practice has become mainstream.

Innovations often succeed in going to the take-off and part of the acceleration phase, often in the form of a demonstration project, but ultimately fail in competing with the established socio-technical system. Therefore, Brown and Keath (2008) have argued that sustainability practitioners and strategists should focus more on providing the capacities and tools for replication and improvement of demonstration project rather than just the demonstration of technology itself.

Studies of historic transitions have been an inspiration for sustainability scholars to advance purposive sustainability transitions (Smith and Stirling, 2008). Empirical historic patterns of sociotechnical change may inform strategies, measures and learning mechanisms to facilitate the growth of sustainability niches towards a new regime. This is the focus area of transition management.

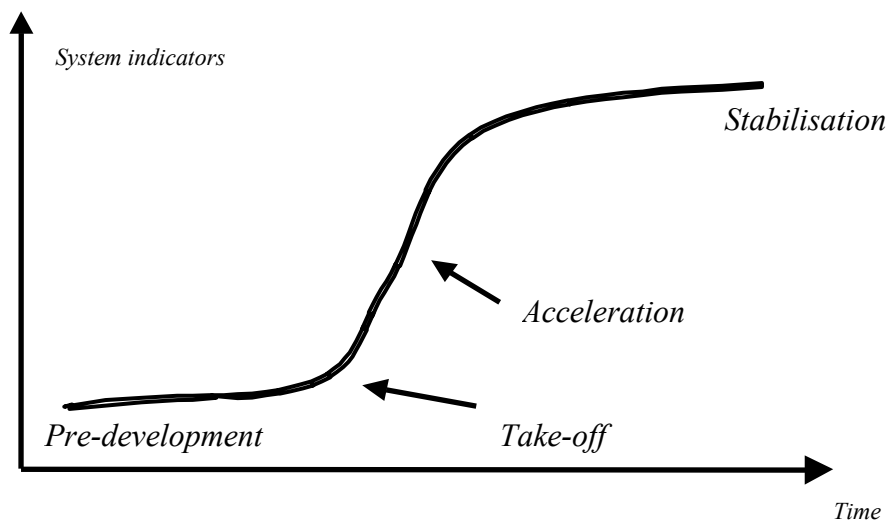


Figure 7.3 Four phases during a transition of a technical system (Rotmans et al., 2001)

7.4.2 Managing transitions

Transition management (Rotmans et al., 2001, Loorbach, 2007) regards society as a patchwork of Complex Adaptive Systems. The approach acknowledges that structural changes in society that may take decades to develop are necessary to realise a more sustainable system. For these structural long term changes, long term envisioning processes are important. This is in contrast with the regular policy process, in which the focus is often short term.

Transition management is a cyclical coordinated multi-actor process at strategic, tactical and operational levels and is organised around four co-evolving activity clusters (1) the development of a transition arena and the development of a long term vision; (2) developing coalitions of stakeholders, transition pathways and agendas, (3) mobilizing stakeholders and knowledge development through experimenting and (4) monitoring and evaluating of the transition process (Loorbach, 2007). The selection of capable individuals of the relevant stakeholders, both regime and niche actors, is an important component of transition management and an essential task of the transition manager.

Multi actor policy making and long term envisioning enable the mobilisation of resources that are required to destabilise the regime. Agenda building is a strategic process that is targeted at building momentum to change large socio-technical systems. Experimenting and innovation aim at improving technologies to increase their competitive advantage. In addition, these activities contribute to the formation of networks. Evaluation of technical demonstration projects aims at improving and replication of technologies in order to mainstream these innovations by knowledge diffusion and learning.

In particular, demonstration projects and transition experiments are important to develop knowledge and experience with local water supply and local flood control solutions to reduce vulnerability. Implementing demonstration projects is a search and learning process for involved actors to deal with new technologies, new roles, new responsibilities and new organisational arrangements. A transition process to multi-source local water supply has consequences for the local water system, the local built environment and the responsible organisations, such as municipalities and waterboards. This requires new roles for municipalities, waterboards, housing cooperation, building contractors, and residents. In the current situation of large scale, centralised water supply, not all of these actors are actively involved.

Components of the transition management approach are also proposed by other researchers that are studying change processes in urban water management. Pahl-Wostl, (2006) states that the formation of informal networks, negotiation processes and coordination among stakeholder groups are essential. According to Meijerink and Huitema (2007) strategies to influence transitions include: the development of new ideas, formation of coalitions and selling of ideas, recognition and exploit windows of opportunities, development and manipulation of venues in modern societies, and orchestration and management of networks. This corresponds with the observation of scientists in the adaptive governance of socio-ecological systems, for instance Olsson et al. (2006) that informal networks and change agents can prepare a system for transitioning by exploring new options and developing strategies.

An obvious observation is that transition management is a normative activity. It aims to 'destabilise' the current regime and replace it with a more sustainable regime that grows out of micro scale sustainable transition experiments. Moreover, as addressed in chapter 1, the concept of sustainability itself is ambiguous and normative. Critics of transition management have questioned the legitimacy of this form of governance (e.g. Shove and Walker, 2008). A question is who is governing the transitions on behalf of whom? Visionary frontrunners develop the agenda

that will have a huge impact on society if they are successful. This can be considered an elitist technocratic approach (Hendriks, 2008). On the other hand, maintaining the status quo in water management also keeps a technocratic regime in place with hardly any form of public participation. Therefore important questions for future research are how transition management should be linked to the formal political decision making process (Smith and Stirling, 2006) but also what role public participation and scientists should play in transition processes.

7.5 Receptivity continuum

The multilevel perspective and transition theory assist in understanding the process of technology adoption at the level of a socio-technical system. However, this provides limited understanding why individuals or specific organisations apply or do not apply innovations.

Environmental concern and the observation that sustainable decentralised urban water management technologies are only introduced very slowly, have led to a large number of publications on decision support systems in urban water management (e.g. Ashley et al., 2004; Sakellari et al., 2005). These systems are valuable tools to support stakeholders to make better decisions and include environmental considerations in the decision making process.

In general, decision support methods are based on the assumption that stakeholders make choices based on rational decisions and that consequences of choices are a priori known and can be valued. The central assumption is that if stakeholders in urban water management make better decisions, the result will be a more sustainable urban water system.

The economic based rational choice model has been criticised by many scholars. Simon (1955) argued that due to the lack of knowledge and uncertainty with regard to consequences of actions, rational decisions often cannot be made. Neither can all consequences of decisions be valued in monetary terms. In addition, stakeholder preferences are dynamically influenced by the decision making process. As Bromley (2004:84) states: ‘Individuals and groups work out what they want by working out what seems reasonable and possible to have.’ This suggests an important role for the willingness of individuals and organisations that are expected to adopt new technologies, as well as the process that influences the preferences of these stakeholders. The model of receptivity (Jeffrey and Seaton, 2003) originates from technology transfer policy studies. Brown and Keath (2008) propose it as one of the concepts from social theory that may assist in understanding and promoting mainstreaming of urban water management innovations into professional practice.

7.5.1 Framework

Jeffrey and Seaton (2003) defined receptivity as “the extent to which there exists not only a willingness (or disposition) but also an ability (or capability) in different constituencies (individuals, communities, organisations, agencies, etc) to absorb, accept and utilise innovation options.” For mainstreaming of new professional practices and alternative technological options, four attributes are required according to the receptivity framework:

- Awareness: being aware that a problem exists, and that alternative options are available
- Association: associate these options with the stakeholders own agenda and objectives
- Acquisition: being able to acquire, implement, operate and maintain the alternative options
- Application: having sufficient legal and financial incentives to apply the alternative options

The understanding of the capacity of the social environment in which policies or technologies are to be implemented is crucial for the success of implementation. The technology or policy should fit into the values, knowledge and capacities of the recipients of change programs. Receptivity analysis focuses on the perception of those who are to implement a new technology or innovation. Jeffrey and Seaton argue that: "It is not possible to understand the response and behaviour of people to an artefact, situation or policy instrument without understanding their perceptions, attitudes and the agendas for change that are relevant for them."

Current reform interventions in urban water management often fail to address the complete range of receptivity. They seem to be focused on creating awareness or stimulating of application by legal reforms and subsidies. Therefore it is not surprising that these programs have received criticism for not being effective (Brown and Keath, 2008). The focus on awareness and application may be explained by the clear, short term results that these programs aim to produce. An awareness campaign or a new subsidy program can be implemented relatively quickly and is a short term identifiable action for public decision makers. On the other hand, creating association and acquisition among stakeholders is a long term process without clear short term results.

7.5.2 Improving receptivity

Mainstreaming of urban water management innovations is only possible if the intended implementers are convinced of the attractiveness of these innovations and have the skills and capacity to implement and maintain them. Therefore, capacity building has been proposed as one of the most important activities for mainstreaming of innovations in urban water management (Brown and Keath, 2008). Capacity building should include an assessment of the receptivity of the required stakeholders. Receptivity may vary considerably among stakeholders and therefore a wide range of adjusted tailor made, specific approaches should be developed. The current -one size fits all- overarching policy interventions to change urban water management are less suitable for this purpose.

In Australia, capacity building programs such as Clearwater in Victoria and New WATERways in Western Australia aim to enhance the capacity of stakeholders to implement, operate and maintain urban water management innovations in practice. Activities of these programs include: bus tours, trainings, workshop, development of manuals and guidelines. Changing conventional practice requires strengthening four components of institutional capacity: (Brown et al. 2006)

- Human resources: implicit and explicit knowledge, skills and expertise available
- Intra-organisational capacity: processes, systems, culture and resources within organisations to cooperate
- Inter-organisational capacity: agreements, relationships and networks the exist between organisation to cooperate
- External institutional rules and incentives: the regulations, policies and incentive schemes

7.6 Mainstreaming urban water innovations: comparing case study observations with literature

In this paragraph the case study observations from part 1 of this thesis are compared with findings from literature. Large technical systems theory shows that established systems are far more competitive in attracting resources than competing systems. Regime stakeholders will not support innovation if it is a threat for the current system. This corresponds to the observation in the local water resources case study. The water utility community is not convinced of the benefits

of local water resources. The multilevel perspective demonstrates that macro level drivers can put a regime under pressure to develop alternatives. This was reflected in all three case studies. Environmental awareness, urbanisation, energy scarcity and climate change were macro level drivers to explore new technologies. Transition management stresses the importance of long term envisioning and long term ambition. In the case of urban water as energy source the long term ambition to become a CO₂ neutral municipality by 2027 was an important driver. The long term ambition of Rotterdam to become a watercity in 2030 facilitated the adoption of floating structure technology. The receptivity continuum demonstrates that awareness is not sufficient for the adoption of technologies. The case study observations also clearly indicate that the association of technical options with the agenda of stakeholders is crucial.

The comparisons between the case study observations and literature findings can be clustered according to two key conditions for mainstreaming of urban water management innovations. The first key condition is stakeholder receptivity to these innovations. The second key condition is including innovations in the urban development process.

7.6.1 Receptivity to urban water management innovations

Chapter 6 on floating urbanisation addressed the lacking experience and lacking receptivity as an obstacle for further diffusion of this technology. Also in chapter 4, lacking receptivity was an obstacle for the application of local water resources. There was no sense of urgency for water scarcity. In addition, the water utility community was not convinced of the benefits of using local water resources. In chapter 5, on the other hand, the municipal experience with another innovative project created a window of opportunity for using the urban water system as an energy source. In literature, human resources and organisational capacity building in urban water management is mentioned as a potential strategy to address the lack of receptivity. This may include training, workshops, capacity building programs and demonstration of innovative practice (Brown and Clarke, 2007). Another option is including new technologies in education curricula (Hunt and Rogers, 2005).

Another obstacle that was identified in chapter 6 was the lack of knowledge of water quality impacts of floating urbanisation. In literature, reliable scientific and technical urban water management knowledge is identified as an enabling factor for application of urban water innovations. This knowledge needs to be made available to professionals by bridging organisations to make an impact on practice (Brown and Clarke, 2007). In the Heerhugowaard local water resources case study, the lack of involvement of other stakeholders in decision making processes about the future of urban water supply was an obstacle. In urban water management, more and more collaborative approaches are used. Chapter 1 mentioned multiple literature sources that stress the importance of stakeholder involvement, in particular for local water management solutions. Trust between stakeholders has been proposed as an essential condition for collaborative processes in urban water management (Rijke, 2007). The capacity between organisations is strengthened by networks of cooperation. The presence of a coalition between stakeholders is a component of institutional capacity to implement urban water management innovations (Söderberg and Johansson, 2006). Therefore, water management knowledge of other stakeholders becomes increasingly important.

In chapters 4 and 5, the high percentage of surface water was a reason to study alternative functions of the water system in Heerhugowaard. Based on comparative case studies between Australia and the Netherlands, Rijke (2007) found that location characteristics of urban development projects can provide opportunities for innovations in urban water management.

This is an indication for an important role of local urban water system knowledge. The same study described agreements and contracts as an enabling factor to realise collaborative projects. Also Söderberg and Johansson (2006) stress the importance of an explicit division of responsibilities and risks among stakeholders. They regard it as a critical demand for successful implementation. Consequently, juridical and administrative knowledge is an important factor for application of innovations in urban water management.

Both in Heerhugowaard (water as energy source) and in Rotterdam (floating urbanisation), experiences in case studies suggest an important role of enthusiastic individuals in promoting the adoption of innovations. In urban water management literature, the role of change agents or champions has been mentioned as a key success factor (Söderberg and Johansson, 2006; Brown and Clarke, 2007; Rijke, 2007; Taylor, 2009). Change agents can function in a supportive organisational culture and if they are facilitated by managerial and political commitment. This is reflected in the Heerhugowaard case study in chapter 5. The high ambition of the municipality for reducing CO₂ emission provided a window of opportunity for change agents to apply new technologies.

Chapter 1 gave a strong indication of the increased importance of the role of citizens in urban water management, in particular if local solutions are implemented. The examples of Japan in chapter 3 showed that vulnerability is reduced by creating risk awareness, expertise and skills among citizens. Hegger (2007) found that citizen-led niche experiments help to explore where the boundaries for socio-technical change are. In the Netherlands, recent research showed that 17% of the people that were looking for a new house were interested in taking a principal role in the building process rather than purchasing a finished house from a project developer (VROM, 2007).

Chapter 6 mentioned government policy and regulations as drivers for mainstreaming of floating urbanisation. In the Heerhugowaard local water resources case study, the restrictive government policy was an obstacle. External rules may include guidelines, subsidies and rules (Brown et al., 2006). In Japan, standardisation of infiltration facilities, design manuals, binding targets, subsidy systems and obligatory water recycling for large projects have contributed to the establishment of a market for ecoproducts. In Victoria, Australia, the adoption of Clause 56 to include stormwater quality improvement in all new residential development is a key incentive to realise urban water management innovation (Rijke, 2007). In the Netherlands, the water assessment is a process instrument to include water interests in the spatial planning process from the beginning (Van Dijk, 2008). Also legislation on Energy Performance (EPC) of new houses is a driver for sustainable energy technologies to increase energy efficiency of houses.

In Heerhugowaard, the use of urban water system for energy supply was a potential solution for the financial feasibility problem of the project exploitation. On the contrary, the financial benefits of using local water resources were low compared to the costs. The example of mainstreaming of floating urbanisation in chapter 6 illustrated how financing mechanisms and legislation have contributed to the success of this innovation. In urban water management literature, the commercial viability of urban water management options by a good business case is a key condition for the application of new technologies in urban water management (Brown and Clarke, 2007; Rijke, 2007). To stimulate the market, water taxes could be made dependent on the surface of paved area per house that is connected to the sewer system (Parikh et al., 2005). Also binding targets and strict environmental legislation may stimulate the development of a commercial market in urban water management innovations.

Perceived risks and real risks are still obstacles for the application of floating urbanisation and using local water resources. Rather than giving subsidies to stimulate technology application, the

government may diminish the risk for private developers to apply innovation. An interesting example is the Lynbrook Development was the first project in Australia where Water Sensitive Urban Design was applied at a large scale. To get the project started, the authorities had to underwrite the reestablishment of a conventional system in case the innovative system would fail (Lloyd et al., 2002). Another way of reducing risks is by giving projects the status of experiments. In transition management theory (Loorbach, 2007) experiments play an important role. They may be created by flexible interpretation of legal frameworks that are obstacles to the implementation of innovations.

7.6.2 Including urban water innovations in spatial development

The frameworks that were discussed in this chapter so far provide understanding in the mechanisms of technology adoption at the technical regime level, and by individuals and organisations. Another requirement for innovations to eventually become mainstream, is that they are included in the urban development process. The innovations of chapter 4-6 that succeeded in making an impact on practice all started as research projects but were eventually included in official urban development decision making processes. The innovations that were eventually included, contributed to urgent local problems such as a threatened project exploitation due to a high percentage of surface water, the municipal ambition to become a CO₂ neutral municipality, or urban renewal projects. This was the case for urban water as energy source and floating urbanisation. Innovations that did not connect to an urgent problem, for instance local water resources were not included in urban development processes.

Currently, urban water infrastructure planning is a deadline driven process that demands proven, on-the-shelf technologies with listed suppliers and certain delivery times. This often excludes innovative options to be considered and developed. In urban development, the context of technical project is reduced to legal boundary conditions, restricted spatial zoning and procedural requirements for environmental impact assessments. Technical project descriptions are further fragmented into sub activities that are tendered to contractors. In most cases contractors win a contract based on the lowest costs. This mechanism is further reinforced by European legislation that prescribed European tendering for all public works projects exceeding a certain expenditure level. It excludes technical options that are not yet competitive with regard to investment costs while neglecting maintenance and operational costs.

The urban development process has been described by a number of urban water management researchers (Söderberg and Johansson, 2006; Van de Ven et al., 2008; Starkl et al., 2009). Generally, the process consists of the phases of spatial planning, authorisation, location development, feasibility study, design and building preparation, building process and maintenance phase. Urban water management innovations are required to go through the whole process to become realised and retain their functioning. Although stakeholders might agree on implementing a certain technology in the spatial planning phase, these intentions may be lost during the feasibility study when the option with lowest costs is often chosen (Starkl et al., 2009). Even if an innovation makes it through the feasibility study, the contractors need to be able to construct the facility in such a way that it works as was planned and that it is delivered in time. Finally, the municipality or waterboard needs the knowledge and capacity to maintain these new technologies.

Many urban water management researchers have developed approaches for transdisciplinary cooperation in urban development processes. According to Van de Ven et al. (2006) planning, design and implementation of urban water infrastructure is a combination of three problems: a

design problem, a negotiation problem and an optimisation problem. In urban water management a so-called three track approach (Van de Ven et al., 2006) should be applied. This approach encompasses finding a good technical solution through optimisation, including this solution in a well-designed urban area, and achieving agreement about design, financing, operation and maintenance through negotiation. Central to the three track approach is the integration of technology, spatial design and negotiation. Müller et al. (2005) proposed the integration of three languages for transdisciplinary learning. These languages are design, science and deliberation. Transdisciplinary cooperation between spatial planners and water experts is also mentioned by other researchers as key condition for change in urban water management (e.g. Mouritz, 1996). Geldof (2005) proposes parallel plan making in which the knowledge of citizens and maintenance experts are incorporated in the design phase. This allows for the transfer of implicit knowledge and transdisciplinary learning between planners and engineers. In addition policy makers and designers should be involved and feel responsible for the construction to safeguard the original intentions. In Melbourne, a two year handover period requires developers to deliver quality when they construct urban water innovations (Rijke, 2007).

Continuity in the process is a requirement in connecting water management and urban development (Van Eijk, 2003). Due to the many staff changes during the urban development process this continuity is permanently at risk. Only by active knowledge management discontinuities can be prevented (Van de Ven et al., 2006).

7.7 Synthesis

7.7.1 A critical reflection

The overview of theories on innovation in this chapter on applications is not exhaustive. One of the objectives of this thesis is to develop recommendations and strategies to achieve mainstreaming of innovative concepts in urban water management. This chapter mainly discusses theories that offer insights to develop such recommendations and strategies. Examples are transition theory and the receptivity framework. These theories assist in understanding the process of technical change. Based on this understanding, subsequently strategies and approaches to influence technical change can be developed. This could be considered a rational approach. Another perspective on technical change in urban water management is to look at it as a chaotic process of innovation that cannot be managed. Serendipity and emergent patterns can play an important role in innovation processes. Urban water systems are complex adaptive systems that show a high degree of self-organisation (Geldof, 2005). The effects of interventions in this kind of systems cannot be predicted. Moreover, these systems cannot be managed from the outside.

Although there seems to be a contradiction between the theories in this chapter and the theories of technical change that have been informed by chaos theory and complexity science, there are many similarities. Complexity governance forms the theoretical basis of transition management (Loorbach, 2007). The importance of diversity is important in complexity governance but is also acknowledged by many of the approaches that were discussed in this chapter such as the multilevel perspective. Diversity is also a key requirement to reduce vulnerability.

Transition management approaches stress the importance of frontrunners. However, according to some researchers (e.g. Smith et al., 2005) the approaches still tend to neglect the role of agency. The receptivity framework can fill this gap because it is agency focused rather than process oriented. The process of technology application may be hard to manage. However, the

receptivity framework shows that by improving the capacities and skills of stakeholders in urban water management, it is still possible to facilitate the uptake of urban water management innovations.

7.7.2 Towards niche-regime interaction

Demonstration of technical and economic feasibility will not necessarily lead to widespread application. Although many proven urban water management technologies are available to realise less vulnerable cities, most projects are still focused on incremental change. In addition these systems are focused on optimisation. Table 7.2 indicates that in order to go from niche management to niche regime interaction, replication, evaluation and capacity building to address the full receptivity continuum are important factors. Also charismatic opinion leaders are necessary with connections to both the micro level innovation projects and the macro mainstream policy level. Only they are able to influence the belief system and the value set of contemporary society. New institutional mechanisms are required to enable project financing, implementation, operation and maintenance of multi functional water systems with multiple stakeholders. At this moment the technical research and development in urban water management is still focused on isolated technical facilities, although it is increasingly linked with other societal objectives such as social amenity and recreation. A next step would be to integrate water management functions in every single aspect of the environment, society and economy. If roads, roofs, buildings and park all have water management functions such as infiltration, retention and purification, isolated technical facilities are no longer necessary.

Table 7.2 Policy interventions described from the perspective of the five regime components of figure 7.2 and the different modes of change policy programs. Transition management focuses on the niche regime interaction to influence mainstream urban water management.

	Conventional Change Policy	Niche Management	Niche/regime interaction
Physical Artefacts	Technology Push	Technical Experiments	Improvement & Replication, self-learning environment
Belief systems	Awareness campaigns	Demonstration Projects	Capacity Building
Water system	Mono functional intervention in water system	Link water objectives to societal objectives	Incorporate water in total urban environment, society and economy
Immaterial Artefacts	New Laws	Create space in legislation	New institutional mechanisms
Actors & Resources	Organisation reform	Frontrunners, Change agents	Charismatic, influential 'Sales agents' and 'Opinion Leaders'

7.7.3 Two key conditions to mainstream innovations

Based on comparing the case study findings from part 1 with the literature survey in this chapter, two conditions are essential for mainstreaming of urban water innovations. These conditions are:

- Including urban water management innovations in spatial planning and development
- Receptivity to urban water management innovations

Including urban water management innovations in spatial planning and development

Urban water management innovations will only diffuse to all interventions in the public and private space if they are included in the urban development process. Thus, integration of water management and urban planning is crucial. Transition theory demonstrates that technologies often have difficulty to get through the acceleration phase. In case the transition succeeds, it takes generations to develop. The process will take place through reinforcing developments in multiple domains, social, cultural economic and technical domains. The multilevel perspective shows that most resistance is situated at the level of institutions, technical systems, culture, and legislation (meso level). Translation of niche developments to the regime is essential for urban water management innovations to become mainstream. This can be achieved by influencing official urban development policy and by evaluation and replication of demonstration projects.

Receptivity to urban water management innovations

A crucial factor for implementation in mainstream practice is the receptivity of professionals and other stakeholders to new approaches, new policies and new technologies. The success of programs that aim to advance the application of a certain policy or technology depends not on the technical quality of these instruments but on the receptivity of the recipients of these change programs. For the full receptivity continuum to be addressed it is necessary that urban water management practitioners are aware of innovations, want to apply these innovations, have the required capabilities, and have sufficient incentives to change their way of working. The mainstreaming process should be supported by the socio-political context. This includes values of organisations and regulations. Capacity building is required to improve receptivity. Capacity building programs should be adjusted to the current level of capacities of stakeholders. Section 7.6 described a number of key factors based on the case studies and literature that contributed to the implementation of urban water innovation. These will be evaluated further in chapter 9.

Outline part 2 of this thesis

The two conditions will be studied as follows in part 2 of this thesis. Chapter 8 presents the results of a policy innovation process in Rotterdam. In this process, niche development successfully influenced regular urban water management policy and urban development policy. Moreover, water management and urban renewal were integrated and a collaborative long term vision was established. Chapter 9 and 10 present the results of a national urban water management survey. Chapter 9 describes the receptivity of urban water management professionals to fundamentally change the urban water system. Chapter 10 specifically investigates the receptivity of urban water professionals to the innovations that were presented in part 1 of this thesis.

8 Case study Rotterdam: linking water management and urban renewal⁷

8.1 Introduction

The previous chapters identified including urban water management innovations in the urban development process is a key condition for implementation. The focus of this chapter is the integration of water retention infrastructures, such as stormwater ponds, canals, infiltration facilities and green roofs, into urban development and urban redevelopment projects. The objective of this chapter is to identify factors that contribute to including urban water management innovations in urban planning.

There are different perspectives possible with regard to urban water infrastructure transformations (Wilsenach, 2006). One perspective promotes improving the current urban water system by developing technological innovations that improve the functioning of the existing system. Others argue that alternatives should be developed that completely replace the current water management and sanitation systems because these systems are inherently unsustainable. The third perspective argues that the urban water infrastructure should gradually transform by integrating water infrastructure investments with urban revitalisation programs. This is called the transformative perspective in this chapter. This perspective requires a form of integrated urban water management. Integrated water management encompasses the whole urban water cycle, including groundwater and surface water, transportation and treatment of water, wastewater and storm water.

Multilevel analyses of historic urban water management transitions (Van der Brugge et al., 2005; Geels, 2005; Geels, 2006) point to the importance of the niche-regime interaction in transition processes, but they provide limited insight on how this may change current and future water infrastructure. The aim of this study was to study how niche developments may influence the urban water management regime. More specifically the aim was to find out how niche developments can be taken up into mainstream urban water management and urban planning.

This research focused on the city of Rotterdam. The chapter first presents the regime developments in urban water management from 1989 to present. Secondly, this chapter describes how a small policy niche (Rotterdam Watercity 2035) emerged that promoted to transform water infrastructure by utilizing the windows of opportunity in urban planning programs. Thirdly, this chapter elaborates how this policy niche successfully influenced the water management and urban planning regime. In the discussion, this chapter presents general key factors that contributed to the inclusion of urban water management innovations in urban planning.

8.2 Case study background

The urban surface water system of Rotterdam can be subdivided into three parts: the floodplain, the polder water system, and the regional canal system (or in Dutch: boezem). The riverbed area is not protected by dikes, instead, flood control is achieved by artificial land filling; in some cases up to 5 meters of sand above Mean Sea Level (MSL). The average tidal movement of the river near the centre of Rotterdam is -0.25 to +1.15 m MSL. The dikes near the city centre are on

⁷ This chapter is based on: Van der Brugge, R. and De Graaf, R.E.: Linking Water Policy Innovation and Urban Renewal. The case of Rotterdam, the Netherlands. Accepted for publication by *Water Policy*

average +5.5 m MSL. The most important economic functions in this area are industry and port activities.

The second part is the polder water system. These areas are situated below MSL and are protected by dikes. Surface water levels are artificially managed at fixed targets. Pumping stations drain water from the polder areas directly to the river (southern part of Rotterdam) or indirectly via canals to the river (northern part of Rotterdam). Most urban functions are located in the polder area. For flood safety, it is therefore important to maintain target water levels.

The third part is the regional canal system. This is a series of canals that function as drainage medium for the polders. During dry spells the water flow can be turned around and the river supplies water to the regional canal and polder systems in order to maintain water quality and compensate for evaporation. The water levels of the main canals are higher than the polder level.

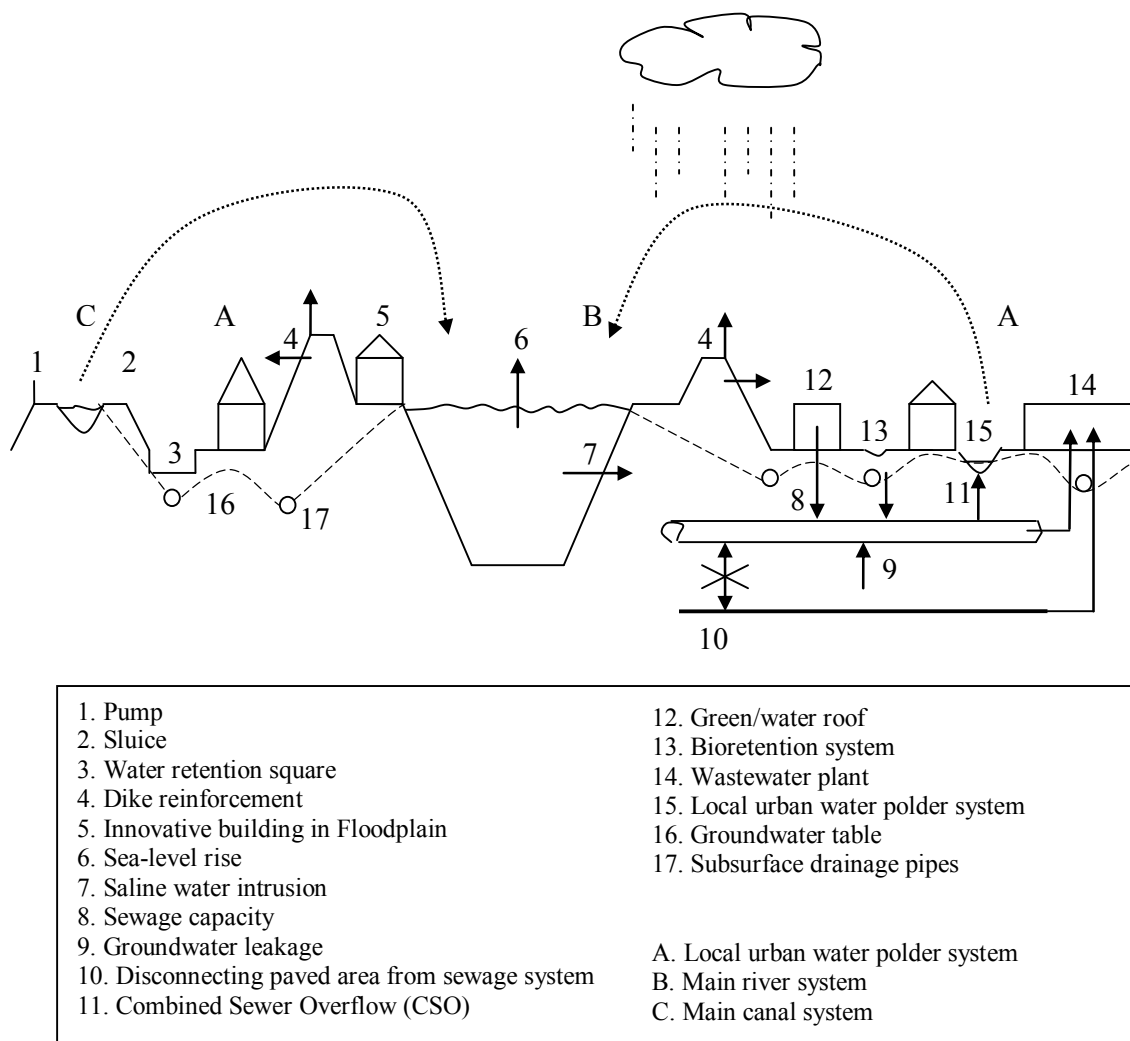


Figure 8.1 Schematisation of the Rotterdam urban water system

Table 8.1 Relevant stakeholders in the Rotterdam urban water governance system

Actor	Abbr	Responsibility in Rotterdam	Activities
Ministry of Transport, Public Works and Water Management	V&W	<ul style="list-style-type: none"> - Flood protection and water management of main river system - Supervision on implementation of European Water Framework Directive (EWFD) 	Drawing up national water policy and legislation
Ministry of the Environment and Spatial Planning	VROM	<ul style="list-style-type: none"> - National housing policy and spatial planning. Environmental affairs - Regulation on drinking water supply 	<ul style="list-style-type: none"> - Policy and legislation on housing, spatial planning (including water retention) and environment. - Determination of drinking water quality standards
Waterboards <ul style="list-style-type: none"> ▪ Delfland ▪ Hollandse Delta ▪ Schieland and Krimpenerwaard 	WS HHHD WSHD HHSK	<ul style="list-style-type: none"> - Water quantity management of main canal system and polder system - Water quality management including wastewater treatment - Flood protection 	<ul style="list-style-type: none"> - Drawing up policy plans - Executing water assessments - Operation and maintenance of flood defence infrastructure and wwtp's
Municipality of Rotterdam	GR	<ul style="list-style-type: none"> - Land use planning 	<ul style="list-style-type: none"> - Drawing up legally binding Land Use Plans
Municipality of Rotterdam, department of public works	GWR	<ul style="list-style-type: none"> - Sewer system - Public space maintenance - Urban infrastructure - Groundwater management (limited) 	<ul style="list-style-type: none"> - Drawing up municipal sewer plan - Drawing up Waterplan Rotterdam - Operation and maintenance of sewer system and other infrastructure and public space - Collecting and transporting excess groundwater from allotment boundary
Municipality of Rotterdam, department of planning, housing and urban design	DS+V	<ul style="list-style-type: none"> - Spatial planning - Housing - Urban functions - Urban landscape design 	<ul style="list-style-type: none"> - Designing and planning urban renewal projects and new urban areas - Drawing up spatial plans
Municipality of Rotterdam, department of economical development and project development	OBR	<ul style="list-style-type: none"> - Project development - Economical development - Real estate management and development 	<ul style="list-style-type: none"> - Developing new urban areas and urban renewal projects

The main sewerage system is a combined system, which transports urban runoff and wastewater in single pipelines to the wastewater treatment plants (WWTP). These pipelines do not have sufficient capacity to transport rainwater during intensive rainstorms. As a result there are combined sewer overflows (CSO's) into the surface water, approximately three times a year on average. Surface water area is limited (in the city centre only 1%) and highly fragmented. Due to the CSO's and stagnant water, urban surface water quality is poor. Much of the sewer infrastructure has been constructed in the post-war reconstruction period of the 50's and 60's. Groundwater leakage into these pipes causes a substantial groundwater flow to the WWTP. The exact amount, however, is unknown. In new urban areas and urban renewal areas, improved separate sewer systems are constructed that transport runoff to the urban surface water system and wastewater to the treatment plant. However, due to transportation of the first runoff flush after a dry period, 70% of the annual stormwater volume is still transported to the WWTP. In addition, pumping of CSO discharge to the river takes place by a pressurised pipe system.

Many organisations are involved in managing the Rotterdam water system and related urban planning activities. Table 8.1 presents the involved stakeholders and their responsibilities and activities. The urban water plan is the most important water policy plan, although it is not legally obliged. The urban water plan is made by the municipality and waterboard. It describes the joint ambitions for urban water management and it provides a strategy how this can be achieved. In 2002, the municipalities and waterboards in the Netherlands agreed to make urban water plans for all municipalities (Van der Meide and Van der Werf, 2002). In Rotterdam, the main policy objectives are (Gemeente Rotterdam, 2007):

- To create 600.000 m³ of addition water retention capacity to prevent pluvial flooding
- To apply risk based measures in order to secure flood safety of the riverbed area and polder area
- To accelerate sewer system renewal from 14 kilometres per year (2000) to 40 kilometres per year (2010)
- To introduce flexible surface water levels for improved water storage capacity during dry spells.
- To develop water quality and measures to comply with European Water Framework Directive

8.3 Methodology

8.3.1 Theoretical framework

Transition theory is used in this chapter to explain why and how urban water infrastructures might transform. The multilevel perspective provides an analytical framework to study change processes within different layers of a large socio-technical system and interaction between these layers. Both theories were discussed in chapter 7.

8.3.2 Data Analysis

To describe changes in the water management regime and to evaluate the interaction of this regime with the policy niche of the Rotterdam Watercity 2035 project, a number of steps were taken in this research. Diffusion of the planning approach of the Rotterdam Watercity 2035 project was analyzed. In particular, the case study focused on the role of this policy niche on

mainstream urban water management policy. Specific attention was paid to analyze if innovations and ideas were taken up in official urban water management policy.

Local water policy documents, urban planning documents, internet resources and project plans were analyzed. In a transformative planning approach, the connection between water management and urban planning and development is an important element. Therefore, close attention was paid to water management themes in the urban planning documents and urban planning themes in urban water management documents.

To analyse diffusion of the transformative approach from the municipal level to the local level, also local council planning documents and projects plans were analyzed. To verify the outcomes of the analysis, and to evaluate on ground implementation of policy objectives, the author participated in two field trips, an interdisciplinary design workshop of the municipality, and took oral interviews. This provided further information whether the approach was limited to paper documents, or that it was internalised in the daily practice of water management and urban planning professionals. The design workshops, in which a new water management plan was drafted, provided insight in how the transformative planning approach was used in practice.

A number of questions were sent to the interviewees in advance to enable preparation of the interview. During the interview, the question lists was used to check if all questions had been answered. Relevant stakeholders in collaborative urban water management and urban renewal projects in Rotterdam were interviewed by using semi-structured interviews. This allowed for specific topics to be further addressed and provided flexibility for unanticipated yet relevant research findings. In total, 16 key individuals of crucial stakeholders were interviewed. These stakeholders had played an important role in the Water City 2035 process or were implementing follow up projects.

The individuals were identified through policy documents and peer recommendations. Interviewees were affiliated with waterboards, social housing corporations, consultancy firms and several departments of the municipality at middle to senior level positions (executives, project leaders, or senior advisors). The interviews were recorded and transcribed by the researchers. The results from the interviews were analyzed and systematically compared to the findings from the policy documents and previous interviews.

Close attention was paid to find contrary evidence; in that case more questions on this topic were included in the next interview. The research findings were captured in a document that was sent to three key-individuals from different departments of the waterboard and municipality for verification. Their feedback was used to produce an accurate representation of the developments in Rotterdam.

8.4 Results

8.4.1 Regime developments urban water management (1989-present)

The first important change took place in 1989. The 3rd National Policy Document on Water Management proclaimed that the responsibility for urban surface water management was to be transferred from the municipality to the waterboards (Ministerie van Verkeer en Waterstaat, 1989). This shift was caused by the rise of integrated water management during the 1980's. This approach emphasised the interrelations between water quantity, water quality and ecology and stressed the necessity of cooperation. Traditionally, waterboards had focused on the rural area. The transfer of responsibility took place during the next 10 to 15 years. In Rotterdam, an attempt to transfer the responsibility was made in 1996, however it did not succeed. The waterboards and

the municipality were unable to agree on the price of assets. In addition, the waterboard claimed that there was a lack of maintenance. This would require additional effort and it would cause higher waterboard taxes. Finally, when consensus was reached, the transfer succeeded in 2001.

The municipality developed the first water management plan (WP1) in consultation with the waterboards in 1998 and 1999. There were two reasons to produce this plan: (1) the upcoming transfer of surface water management to the waterboards; and (2) the 40-year old sewer system had to be replaced and renewed. During the preparation phase, the municipality and the waterboards made a full scale inventory of the urban water system. WP1 formulated for the first time future ambitions for the water system in terms of water quality and ecological quality. The plan addressed overdue dredging, combined sewer overflows and fish mortality. Strategies were formulated to improve water quality, remove polluted bottom sediments, create ecological embankments and implement active biological management of fish populations.

In the Bergse Plassen water quality improved significantly. In the Zuiderpark innovative storm water treatment technologies, ecological embankments and 14 hectares of additional water retention were created. In the north of Rotterdam, the old channels were improved. Sewer emissions to the river were successfully reduced. However, during the implementation of WP1, the waterboards discovered that water retention had low priority in Rotterdam compared to other issues such as economic development, unemployment and safety. Moreover, contrary to the rural surroundings, space for water retention was scarce and expensive. The waterboards realised they had to cooperate and move towards multi-functional use of space to successfully achieve their objectives.

At the end of the 1990's it became clear that the urban water management infrastructure capacity was insufficient. Pluvial flooding in 1998 in Western Holland, the Rotterdam districts included, led to questions in parliament. The committee Tielrooij was appointed for an inquiry on the state of the Dutch water management systems. In their report *Water management in the 21st Century*, the committee argued that the water retention and detention capacity was insufficient (Tielrooij, 2000). The committee proposed to give water a guiding role in regional planning and urban planning.

The water assessment was introduced in 2003. This assessment is a legally binding process instrument to involve and consult waterboards from the initial phases of the urban planning process (Riza, 2003). One year later, the water management authorities in the Netherlands committed themselves to increase water storage capacity. For Rotterdam, this amounted to 600.000 m³ of additional water retention capacity in 2015 and 900.000 m³ in 2050. This amount of water storage could not be realised within the current urban water management infrastructure. In other words, the incremental approach was insufficient to deal with the challenges. In 2003, three departments of the municipality, Public Works, Urban Planning and Economic Development, started a water platform to discuss water issues and look for synergies between urban planning, economic development and water management.

8.4.2 Changes in perception of water managers

The studied policy plans and interviews indicate that in less than twenty years time, the urban water managers made a huge turn in thinking about urban water management. Figure 8.2 presents these shifts. During the Rotterdam Water City 2035 project the last three turns in thinking were made. This project will be discussed below. It became clear that additional water storage capacity in urban environments was impossible without innovative solutions that combine multiple urban functions at one location. One of the interviewees summarised this accurately: "In the old

approach we said: “provide us with the square meters and we will dig canals in a cost-effective way. In the new approach we say: ‘we are open to water infrastructure innovations, such as water retention squares and green roofs.’”

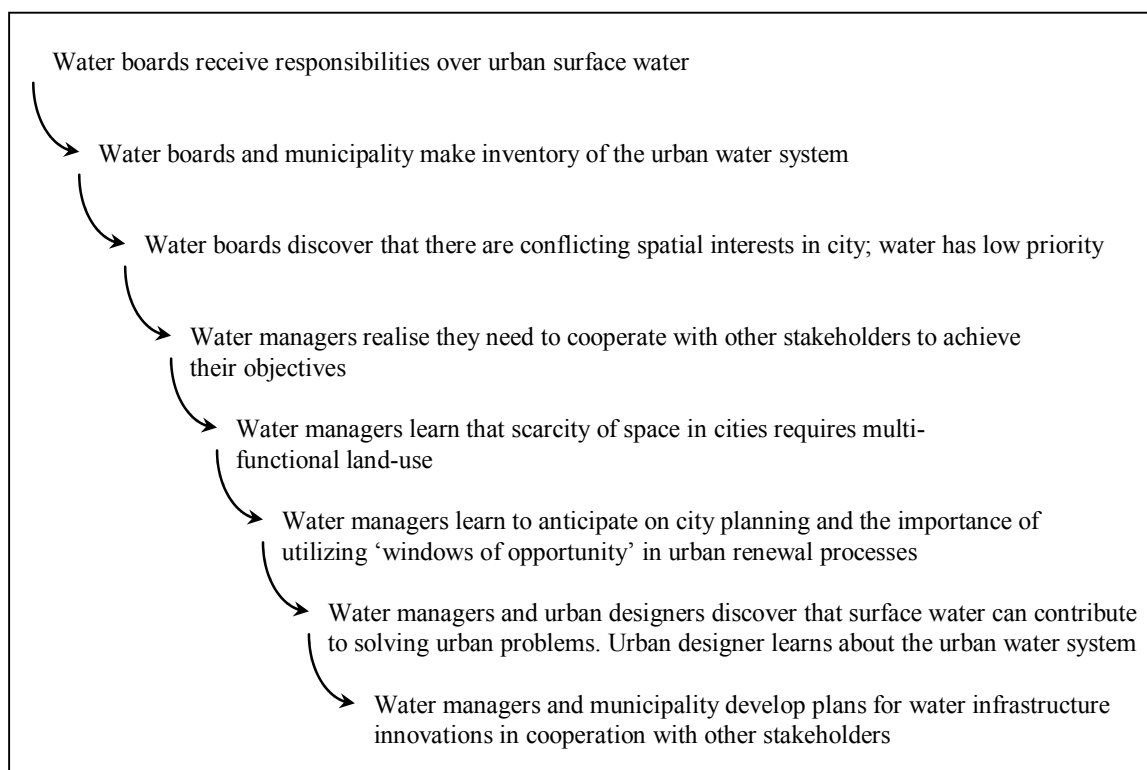


Figure 8.2 Shifts in thinking towards a transformative approach in urban water management

8.4.3 The policy niche of Rotterdam Watercity 2035

The envisioning project Rotterdam Water City 2035 (in Dutch: Rotterdam Waterstad 2035) turned out to be an important step towards a transformative water management approach. During this project an integral future vision on urban design was combined with a climate adaptation strategy. The policy niche was initiated by the 2nd International Architecture Biennale Rotterdam (IABR). The IABR is a prestigious two-year architecture and design event. The 2005 theme was “The Flood”. The assignment of this contest was to design and develop a scale model of the city in 2035. The scale model was developed during an intensive period of two months. As preparation, three studies were carried out in advance to develop a common understanding of the problems and opportunities. The quality of the project was enhanced by the input of system knowledge. This removed the risk of ‘negotiated nonsense’ that can be present in collaborative planning processes, that stakeholders agree on something unrealistic and unfeasible (De Bruijn et al., 2002; Van de Ven et al., 2006).

The objective of the project was to combine the water challenge and the urban challenge. The water challenge was defined as separating clean water and waste water, creating sufficient peak retention capacity, creating seasonal water storage, and creating a denser network of water ways to control ground water. The urban challenge was defined as creating an attractive city for residents and entrepreneurs, stimulating a high social diversity and to strengthen economy vitality.

The selected project leader desired a joint effort of the municipality departments and the waterboards to achieve an integrated approach. Together with the department director, 15 project

members were selected: six designers, five water management experts, one member from economic management department and three members from the waterboards. There was a strict selection procedure of participants. Absence of project team members was not allowed at any meeting by the directors of the involved departments.

The facilitators encouraged project members to translate the future images to strategies and measures. They made the project members understand that it was insufficient to make a design without having a “philosophy in time”. Port activity and industrial activity will be relocated to new sites outside the city in the next decades. This development creates opportunities for water related entrepreneurial activity and development of waterfronts near the city centre. Similarly, current urban renewal plans to revitalise rundown neighbourhoods create opportunities for the incorporation of visible water retention infrastructure in the urban environment. By using these windows of opportunity, waterboards may succeed in achieving the intended increase of water retention capacity.

The actual design encompasses three images: River City for the city centre, Water Network City for the south and Channel City for the north. In River City, the river bed is transformed from an old port area to a thriving place with all kinds of economic initiatives combined with ecological developments and floating houses. Space to raise dikes must be reserved to anticipate on climate change. These dikes will have to be built in accordance with the actual sea level rise.

In Water Network City, the southern part of Rotterdam is transformed into attractive living environment. There is abundant water and nature, attracting a wide diversity of people. A fine meshed water network will be connected to the surrounding waterways. The Channel City design aims to improve existing water infrastructure of channels in the northern part of the city. Exciting water infrastructure innovations are introduced in this area. Squares are transformed into water retention squares to store excess water during periods of heavy rainfall. Buildings with flat roofs have green roofs that are used for water retention and capture dust particles.

Rotterdam Water City 2035 argued that water can contribute to the urban challenge by creating high diversity living environments. Water could upgrade degraded neighbourhoods and attract residents with medium to high education. In addition, water could improve the connection to the surrounding area by interlinking water ways. The following quote in the final report is illustrative: “The water challenge is the urban map of opportunities. The result is not only that the water challenge will be solved but also new qualities are included in the city.”

The non-official status of Rotterdam Watercity 2035 decreased the political risk. If it failed, it would just be a lost contest. The contest created an occasion for a cross-disciplinary cooperation, the generation of extreme ideas and an unusual long time horizon. Possible drawbacks of non-official policy are low status and low priority. However, this was not the case because of high time pressure, the status of the contest, the strict selection of participants and executive support. This result corresponds with the observation in literature that informal networks and change agents can prepare a system for transitioning by exploring new options and developing strategies (Olsson et al., 2006).

Reframing had a significant effect on the cooperation between water managers and designers. They learned to understand each others stakes and cooperate from the start. The designers learned that designing with water was ‘fun’. This was a major shift in thinking, one of the interviewees said that even in 2004 urban designers still considered water as “one of the seven plagues” for the urban designer.

8.4.4 Regime response after Water City 2035

At the final symposium, The Rotterdam Water City 2035 design was awarded the first prize, the Biennale Infrastructure and Construction Award. This further accelerated the process and political support for the ideas grew. To enable the mainstreaming of ideas from this policy niche, they had to be taken up by the mainstream urban water management regime.

Following the prizewinning vision, the Kuyper-motion was submitted in the municipal council. It proposed to develop a feasible program based on the design and time strategy of Rotterdam Water City 2035. The 2nd water plan (WP2) was developed in 2006 and 2007 and is the further specification of Rotterdam Water City 2035 in official policy. Technical innovations, the integrated approach and the long-term climate adaption strategy were included in WP2. The document is a co-production of the waterboards, urban planners and municipal water experts. WP2 was also integrated with the official Urban Development Vision Rotterdam 2030 (Gemeente Rotterdam, 2007).

Projects were started as well as spinoff of Water City 2035. The first green roof of Rotterdam was opened in January 2008 at the building of the municipal archives. The further technical development of water retention squares and a demonstration project for floating urbanisation were also initiated. The fact that the urban water management regime was receptive to the results of Rotterdam Water City 2035, can be explained by a conjuncture of developments that were described in the section on regime developments: (a) the transfer of urban surface water management responsibilities; (b) improved knowledge of the water system; (c) a social learning process among stakeholders that led to a change in stakeholder perceptions; (d) an urgent water challenge of an additional 600.000 m³ water storage before 2015; (e) a large scale urban renewal process of rundown neighbourhoods; (f) and the entrance of urban planners in the urban water management regime.

8.4.5 Niche regime interaction

Although the Rotterdam Water City 2035 project was not an official policy process, it has influenced urban water policy in Rotterdam significantly. One of the interviewees explained: “A mechanism had been initiated, which we had to continue. The end of the planning period of WP1 was a good occasion. Is there any better way than elaborate further on WP1 and add the knowledge and inspiration from the Biennale with the same organisations? The water challenge is now much better understood and the direction where the city wants to go has been made explicit too”. The inter departmental and inter organisational network that emerged out of the Rotterdam Water City 2035 project was an important contributing factor to the integral development of WP2. The WP2 preface illustrates this: “Water management and urban development are inherently linked. If we want to solve the water challenge, then we need to fit this in with urban design and city planning. Similarly, the water challenge can give a tremendous impulse to urban design and planning. A well known example of this synergy is the Rotterdam Water City 2035” (Gemeente Rotterdam, 2007).

The change in urban water management in Rotterdam was facilitated by interplay of a micro scale policy niche and the urban water management regime receptivity to these micro scale developments. This finding is similar to the transition to water sensitive urban design in Melbourne (Brown and Clarke, 2007). The change agents that were interviewed had a couple of characteristics, they 1) were highly motivated to change the current situation, 2) were willing to invest significant amounts of time and energy in the envisioning process in addition to their regular work and 3) were convinced that the water management targets in Rotterdam could only

be accomplished through cooperation and innovative concepts rather than incremental change. The change agents worked for the various organisations that participated in the contest.

During the contest, a network was formed between these change agents that continued to exist after the contest. This enabled further development of the Rotterdam Water City approach in official policy. It was a prestigious project because it received strong executive support from department directors. They were convinced of the importance of the IABR and they needed new ideas to achieve the objectives of water storage. Their support enabled the project participants to spend two days a week on the project. In order to strengthen their support, some directors were invited to visit during the workshops of the project. One of the interviewees explained: “It was clever to invite the directors over to our place, where sweat was in the air [...] and where the floor was filled with coffee cups and the wall was covered with unfinished drawings. The directors thought they still had influence [...] they felt ownership.”

Besides executive support, political support was an important factor. The project team tried to convince politicians to support the Water City 2035 book and write the preface. The project team succeeded and important politicians, including board members of the waterboards, signed the book as an informal way of approval and political commitment. Crucial factor to achieve political commitment was the way the book was written. The identity of Rotterdam as port city, which owes its existence and success to the water system, was an important element. The book did not only present a technical water story, but also a well designed emotional and cultural story, which made it attractive for politicians. The interplay between the policy niche and the urban water management regime facilitated the change process to a transformative approach of urban water management. This corresponds to the observation in literature that the success of niche developments is not only determined by processes within the niche, but also by regime developments rather than direct competition between the niche and the regime (Kemp et al., 2001; Geels, 2002).

8.5 Discussion

8.5.1 Potential and applicability

This chapter demonstrates the importance of a key condition for mainstreaming of innovation: including water management innovations in urban planning. The Rotterdam case confirms various factors that were identified in chapter 7 as contributing factors for mainstreaming of urban water innovations. These factors were derived from the case studies of part 1 and urban water management literature. Similar to the case studies in part 1 of this thesis, making the connection to urgent local problems, in this case urban renewal and water retention, contributed to the receptivity to urban water management innovations. The role of reliable knowledge of the urban water system contributed to a joint system perception and improved water management knowledge of other stakeholders. The availability of networks for cooperation facilitated the inclusion of innovative concepts in urban planning. The key role of change agents was also confirmed in this study, as well as a supportive organisational culture. Also political support for the ideas of Watercity 2035 was important.

To realise more water retention infrastructure in the existing city of Rotterdam, the transformative perspective is used to integrate urban planning and urban water management on a strategic level. The strategies in WP2 were completely aligned with the strategies of the Urban Development Vision. Important for this were changes in the network, for instance the transferring of urban water management responsibility to the waterboard. A major change in the

perception of water managers has taken place. Due to the low priority of water management compared to other issues, they realised they had to cooperate in utilise windows of opportunity in urban development processes. By making the link to the urgent problem of urban renewal, water became a higher priority on the political agenda.

In the long term envisioning process Rotterdam Watercity 2035, the objective was to combine the objectives of urban revitalisation with the objectives of urban water management. Key factors that contributed to mainstreaming were: the high status of the project and the fact that it had no official status. As a result, it became possible to use longer time horizons than the ordinary 5 years planning horizon. In addition, it provided the opportunity to come up with extreme ideas and cross disciplinary boundaries. The non official status also reduced the risks. If it would fail, it would just be a lost contest.

During the Rotterdam Watercity project, an inter organisational network was formed that continued to exist after the project. This network consisted of change agents that 1) were highly motivated to change the current situation, 2) were willing to invest significant amounts of time and energy in the envisioning process in addition to their regular work and 3) were convinced that the water management targets in Rotterdam could only be accomplished through cooperation and innovative concepts.

The network of change agents formed the foundation for the development of the official urban water management policy Waterplan 2. The urban water management regime was receptive to the results of Rotterdam Water City 2035. Next to the factors that were described above, executive and political support for the results created more receptivity within the regime. Therefore many ideas of the project went straight into official policy.

8.5.2 Limitations and obstacles

In Rotterdam, there have been significant cultural and institutional changes. The perception of stakeholders has changed. Urban planning and urban water management are integrated. Despite the success of Rotterdam Watercity 2035, integration of urban planning and water management in infrastructure is still mainly limited to a number of demonstration projects. This is understandable because changes in infrastructure take decades to develop. Therefore, it is too soon to speak of a transition. The developments that were described in this chapter are crucial steps. However, more steps are required to complete the transition. The most important one is connecting strategy and policy making with practice.

The integration of water and urban development in the implementation, operation and maintenance phases of all interventions in the urban infrastructure is a necessary condition for the transformation of Rotterdam to the vision of Watercity 2035. Currently, still projects are executed continuously, that do not include elements such as innovative water retention and upgrading of neighbourhoods by creating water networks. Urban infrastructure has a lifespan of decades; therefore the next opportunity to include these elements in the urban structure will be far away. Policy makers seem to be convinced of the necessity of connecting urban water management and spatial development. Diffusion of this vision to stakeholders that execute urban development projects in the field is required to make the translation to practice.

Examples of stakeholders that are needed to implement the vision are building contractors, project developers and housing corporations. They were not involved in developing the vision of Rotterdam Watercity 2035. However, they are now involved in a couple of follow-up projects. Rotterdam Water City 2035 and WP2 were both developed by a network of change agents. The interdisciplinary approach of these projects needs to be internalised in a broader base of

stakeholders dealing with urban water management and urban planning. Organisational capacity building, or starting learning processes, is a key factor to further advance this approach in urban water management. This observation is also reflected in recent work of urban water governance researchers (Brown and Clarke, 2007). In addition, there will be considerable differences in capacities and commitment among stakeholders. Consequently, capacity building programs should be specifically adapted according to local conditions (Morison, 2008).

8.6 Conclusion

The developments in the water management regime in Rotterdam show that the development of urban water management policy is integrated with urban planning. The role of Rotterdam Water City 2035 has been crucial in changing towards the transformative perspective. In this policy innovation niche, for the first time urban planners and urban water experts, developed a joint long term vision for the city. Because it was a non official policy process, more radical ideas and a longer planning horizon were possible than in official policy documents. In this vision, water retention contributes to the upgrading of neighbourhoods by increasing living quality. Many innovations that were developed in the project were included in official spatial planning policy. Examples are green roofs, water retention squares and floating urbanisation.

Mainstreaming was enabled by changes in the regime during the preceding years. It became increasingly clear the water retention objectives could never be realised in a conventional way. Consequently, urban water management professionals were receptive to the integrated approach that was applied in the project Rotterdam Water City 2035. Mainstreaming was further enabled by executive and political support and the presence of change agents in all participating organisations.

The results of this chapter demonstrate the importance of including urban water management innovation in spatial planning, which was identified in chapter 7 as the first key condition for mainstreaming of innovations. Furthermore, the results confirm the importance of various factors that were identified in chapter 7 as contributing factors for mainstreaming of urban water management innovations. In the next chapters, the importance and quality of these factors will be further evaluated on a national scale.

9 Receptivity to transformative change in the Dutch urban water management sector⁸

9.1 Introduction

Part 1 of this thesis described technologies that use the urban surface water and groundwater in new ways. Because these technologies require fulfilling of new roles of stakeholders, new guidelines, new user practices and new knowledge, they are not incremental improvements of the current system. One of the reasons that implementation of innovative solutions is hindered is the presence of institutional barriers and technical lock ins (Kotz and Hiessl, 2005; Wong, 2006a). To address these obstacles, changing professional practice is mentioned as an important element (Mouritz, 1996).

Chapter 7 identified the receptivity of professionals as a key condition that determines the implementation of urban water management innovations. Since this thesis is not only concerned with the implementation of technologies but in particular with mainstreaming of technologies, this chapter evaluates the receptivity of professionals to transformative change in urban water management. Moreover, factors that were identified in chapter 7, based on case study observations and literature, are clustered according to the receptivity framework and measured in this chapter.

Currently, there are few international examples of research on professional perceptions in urban water management (e.g. Brown and Farrelly, 2007). The aim of this chapter is to develop insights in the potential for transformative change in the Dutch urban water management sector.

9.2 Methodology

9.2.1 Study definition

In order to ensure a common point of reference, sustainable urban water management was defined as “the management of groundwater, surface water and stormwater in urban areas with regard to water quality and water quantity in order to successfully achieve the objectives of the European Water Framework Directive and the National Water Management Agreement. Furthermore, the urban water system optimally enables ecological and social functions against costs that are acceptable to society.” The European Water Framework Directive (EU, 2000) is aimed at achieving good ecological and chemical status in all European water systems by 2015. The National Water Management Agreement (NBW) was signed in 2003 as a joint policy of the municipalities, waterboards, provinces and national government in the Netherlands, to reduce flooding to an acceptable level. The agreement has recently been updated (NBW, 2008).

9.2.2 Framework

The receptivity framework of Jeffrey and Seaton (2003) was applied to analyze the professional perception on change in urban water management. This framework was described in chapter 7. Drawing on urban water management literature, section 7.6 described a number of key factors that contributed to the implementation of urban water innovation. These key factors were

⁸ This chapter is based on: De Graaf, R.E., R.J. Dahm, J. Icke, R.W. Goetgeluk, S.J.T. Jansen and F.H.M. van de Ven (2009). Receptivity to transformative change in the Dutch urban water management sector. *Water Science and Technology* 60(2), 311–320.

summarised to a list of 20 factors and were classified according to the receptivity framework, as shown in Table 9.1. The respondents were asked to value the importance and current quality of these factors in urban water management.

Table 9.1 Key factors that were tested in this survey, classified according to the receptivity framework

Awareness	Acquisition
1. Available knowledge about the local urban water system	11. Trust between cooperating partners in urban water projects
2. Water management knowledge of other stakeholders	12. Experience in connecting water management and spatial planning
3. Reliable scientific knowledge about the urban water system	13. Availability of networks and organisational arrangements for stakeholder cooperation
4. Knowledge of technical innovations in urban water management	14. Quality of design skills in urban water projects
5. Juridical and administrative knowledge in urban water management	15. Quality of negotiation skills in urban water projects
Association	Application
6. Enthusiasm and perseverance of individuals in urban water projects	16. Financial incentives and subsidy schemes from national government
7. Support and commitment of elected officials to sustainable water management	17. Accountability frameworks for stakeholders in urban water management
8. Involvement of citizens in urban water projects	18. A flexible interpretation of legal frameworks
9. Supportive organisational culture	19. Commercial viability for private organisations of technical innovations
10. Availability of a national overarching vision for urban water management	20. Binding targets for water quantity and water quality

9.2.3 Participants

Urban water management professionals were invited to participate in an online survey⁹ by the professional organisations of the municipalities and the waterboards. In the Netherlands, waterboards are responsible for flood control, water quality management, wastewater treatment and surface water management. Municipalities are responsible for the sewer system, stormwater management and groundwater management in the public space. The focus of this research was on urban water management and urban drainage, thus water utilities were not included in the survey. The respondents of municipalities are the regional contact persons, the ‘water ambassadors’ for the implementation of the National Water Agreement. A number of 78 water ambassadors were invited to complete the survey. For waterboards, a different approach was chosen. All 26 waterboards were invited to participate in the survey and were asked to distribute the questionnaire to urban water management experts in their organisation. The respondents are

⁹ All questions are available at: www.otb.tudelft.nl/waterbeheer

characterised by: (i) involvement in national and European water policy implementation; (ii) overview of regional urban water management issues due to their representative professional role; and (iii) their knowledge of current issues in urban water management. Thus, the respondents can be considered as policy experts who are working at local level in urban water management practice. Due to the method of selection, the results do not reflect the entire urban water management sector and should be considered as the perception of this specific group. Nevertheless, the results are considered relevant for three reasons. First, the respondents have a good overview and insight in local urban water management issues. Second, as policy experts they perform a role as representatives for the sector. Finally, as opinion leaders they influence their peers' behaviour.

A number of subgroups were distinguished in the survey based on type of organisation, professional experience, level of education, experience with innovative technologies and attitude towards transformative change. This distinction was made to enable testing of significant differences in the practitioner receptivity based on these characteristics.

9.2.4 Procedure

An online questionnaire in NetQuestionnaire with 83 questions was available to urban water professionals in August and September 2008. The respondents did not receive any compensation and participated voluntarily and anonymously in the survey. The questionnaire was developed to investigate the professional perspective on how urban water management has changed in recent years. Topics included emerging themes that have increased most in importance over the last years. In addition, respondents had to indicate which tasks have increased most in size. Other questions examined the perceived importance of new functions of urban water systems. The questionnaire investigated the perceived necessity of transforming the urban water system and both the importance and current status of key factors to achieve sustainable urban water management. The importance of these key factors for change was measured using an eleven-item scale ranging from 0 = *extremely unimportant* to 10 = *extremely important*. Rating of the present quality of the key factors were from 0 = *extremely poor* to 10 = *excellent*.

9.2.5 Data Analysis

The data were analyzed with the Statistical Package for Social Science (SPSS) version 16.0. Descriptive statistics were used to evaluate the importance and present quality of key factors for transformative change. T-tests were executed to find differences in responses based on type of organisation, professional experience, level of education, experience with innovative technologies and attitude towards transformative change. The significance level was set on $P < 0.05$. 'Transition thinkers' were defined in this research as those respondents who believe the present system should be replaced with new concepts and technologies in order to achieve sustainable urban water management. The perceptions of 'transition thinkers' were examined and compared with the mainstream thinkers among the respondents. Some statistically significant differences between groups of respondents were found. The case by case method of dealing with missing values was applied in this research. Thus, all valid answers to individual questions were taken into account in the results that are presented.

9.3 Results

Over a 30 day period a total number of 89 urban water professionals completed the survey. The respondents were working at municipalities (n = 46; 52%), waterboards (n = 26; 29%), consultancy firms (n = 7; 8%), branch organisations (n = 6; 7%) or elsewhere (n = 4; 4%). After the invitation and one reminder, the response rate was 59% for the municipalities and 50% for the waterboards. The majority of the respondents (52%) had between 5 and 15 years experience in the water management sector, 22% of respondents had less than 5 years experience, 26% more than 15 years. A percentage of 90% had a higher education degree on either university level or higher professional education level. More than 95% had a background in either engineering or natural sciences. The respondents were predominantly working as policy advisor, senior policy advisor or project leader. The geographical distribution of the respondents was reasonably balanced, with an equal amount of completed questionnaires from parts of the Netherlands below and above sea level. This prevented a possible over representation in results of certain issues such as flooding (lower parts) or groundwater depletion (higher parts). The distribution of small municipalities (<100,000 citizens; 64%) and large municipalities (>100,000 citizens; 36%) compared to 27% of the Dutch population living in large cities (CBS, 2008).

9.3.1 Recent developments

Respondents were asked to choose water management themes, with a maximum of two, that have increased most in importance over the last years. In addition, they had to indicate which tasks have increased most in size. Overall, results indicate that in recent years three themes have increased most in the importance: spatial planning (35%), water quantity (33%) and water quality (29%). The increased importance of spatial planning in urban water management was acknowledged by respondents from both waterboards and municipalities. Table 9.2 provides specific result of these groups. In general, tasks of which the work load has increased most over the past few years are: developing urban water management plans (32%), water quantity management/ urban flood control (27%) and spatial planning (25%). Respondents were asked to value the importance of strengthening three new functions of urban water systems; connection with urban renewal, contribution to social amenity, and enabling ecological development. Strengthening the connection between urban water management and urban renewal obtained the highest mean ranking; 8.4 on a 0-10 scale. A high importance was placed on enhancing urban water quantity and urban water quality to contribute to social amenity (mean ranking: 8.3). Third was improving the urban water system to improve ecology with an average ranking of 7.1.

Table 9.2 The importance of themes and tasks according to respondents of municipalities and waterboards

	Themes that have increased most in importance		Tasks that have increased most in size	
First	Waterboards Ecology (n=10; 39%)	Municipalities Spatial Planning (n=16; 35%)	Waterboards Water Quality Management (n=9; 35%)	Municipalities Urban Water Plans (n=19; 43%)
Second	Spatial Planning (n=8; 31%)	Water Quantity/ Flood Control (n=15; 33%)	Ecological Management (n=7; 27%)	Water Quality Management (n=13; 28%)
Third	Water Quality (n=8; 31%)	Urban Water Plans (n=12; 26%) Flood Safety (n=12; 26%) Water Quality (n=12; 26%)	Developing Basin Management Plans (n=7; 27%)	Spatial Planning (n=13; 28%)

9.3.2 Sense of urgency

The respondents were asked to choose the two most urgent problems in present day water management out of a list of 19 problems. Respondents were allowed to add a problem to the list. Pluvial flooding, effects of climate change, groundwater nuisance and increase in paved area were considered the most important problems (>10%) by municipal employees. The effects of climate change and lacking citizen awareness were chosen most frequently by waterboard respondents. Notably, the lack of citizen awareness was listed by the respondents themselves.

Problems that were not chosen were: illicit connections of sewer systems, soil pollution, pharmaceutical residuals in water systems, land subsidence, droughts and groundwater over extraction. The sense of urgency that results from the perceived importance of achieving societal objectives in urban water management was tested. The importance of achieving the objectives of the European Water Framework Directive received a medium rating (6.7 on a 0-10 scale). The importance of achieving the objectives National Water Management Agreement received an average rating of 7.6. A significant difference was found between waterboards (8.3) and municipalities (7.4).

9.3.3 Perceived necessity of transformative change

Most respondents considered the objectives in urban water management achievable by optimisation of the current technical system. For the objectives of the National Water Management Agreement a percentage of 59% was found. For the European Water Framework Directive, the percentage was 48%. A minority (n = 7; 8%) expressed the opinion that the replacement of the current urban system with new concepts and technologies is required to achieve the European objectives. This was the case for 2% (n = 2) with regard to the national objectives. The remaining respondents chose a combination of optimisation and replacement, had a different opinion, or did not know. Table 9.3 shows that the majority of respondents felt that adjustments are needed within the urban water management sector and in other sectors. The results also gave a strong indication the respondents do not support detailed binding targets and standards from the national government (81%) as a way to achieve improvements.

Table 9.3 Perceived required adjustments in different sectors to achieve national and European urban water objectives

	Adjustments within the urban water sector	Adjustments in other sectors	Adjustments to both the urban water sector and other sectors	Other/ Does not know
National objectives	11 %	9 %	73 %	8 %
European objectives	6 %	26 %	63 %	5 %

9.3.4 Priority factors to achieve sustainable urban water management

The factors in Table 9.1 were ranked on current perceived quality and of discrepancy between perceived importance and perceived quality. The latter indicates the necessary level of effort to improve the quality to a level that matches its perceived importance. Plotted in a four quadrant diagram, key factors were classified in the following groups.

1. Limited priority: relatively unimportant factors, with a relatively high discrepancy between importance and quality
2. Priority: relatively important factors, with relatively high discrepancy between importance and quality
3. Maintain: relatively important factors, with relatively low discrepancy between importance and quality
4. No priority: relatively unimportant factors, with relatively low discrepancy between importance and quality

Efforts to achieve a sustainable urban water system should be targeted to those key factors that receive a combination of both a relative high importance and a high discrepancy between importance and current perceived quality (second quadrant).

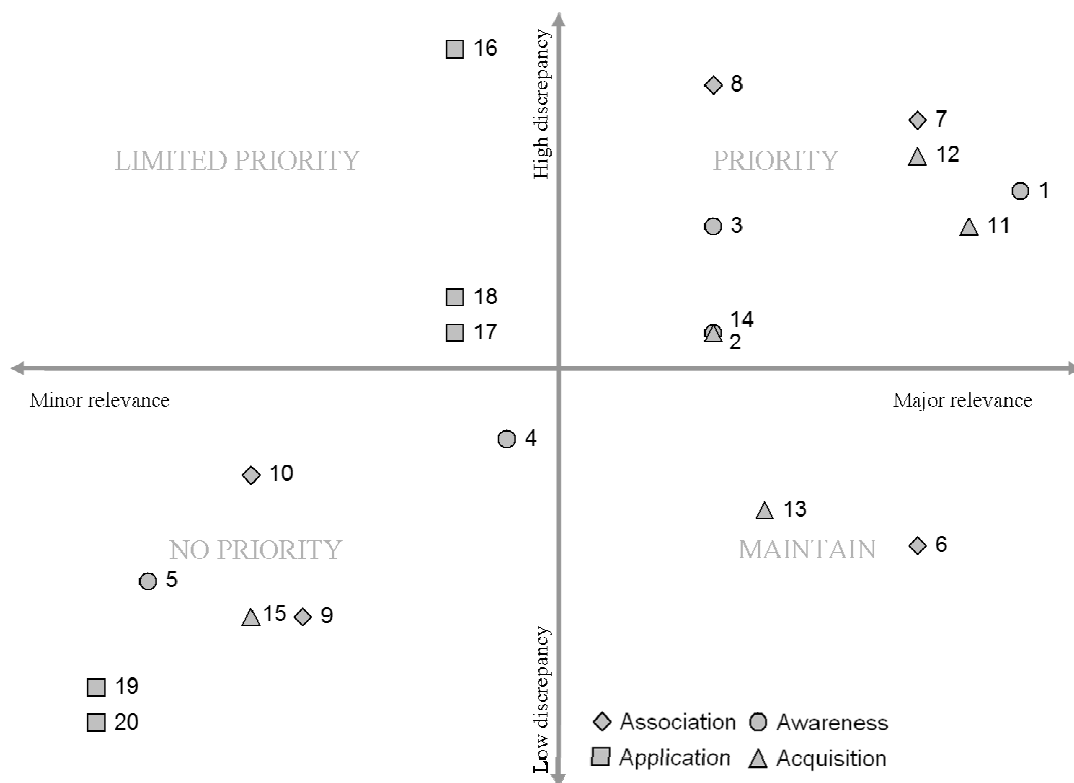


Figure 9.1 Key factors to achieve sustainable water management plotted according to relevance and discrepancy between importance and current quality. Numbers are in accordance with Table 9.1.

Figure 9.1 provides a list of 5 priority factors that should be improved to achieve sustainable urban water management (Table 9.1 explains the numbers): available local urban water system knowledge, trust between cooperating partners in urban water projects, experience in connecting water management and spatial planning, support and commitment of elected officials to sustainable water management, and involvement of citizens in urban water projects. These factors are mainly classified in the association and acquisition categories of the receptivity framework. The other three factors in the second quadrant are also considered a priority however; they are closer to the origin and thus received a lower urgency than the top 5. These factors are:

reliable scientific knowledge about the urban water system, the water management knowledge of other stakeholders and the quality of design skills in urban water projects.

Two factors were considered relatively important but no priority because the current quality is sufficient. These factors are: 1) the availability of networks and organisational arrangements for stakeholder cooperation, and 2) enthusiasm and perseverance of individuals in urban water projects. The two factors that were considered to have the lowest priority are: binding targets for water quantity and water quality and commercial viability for private organisations of technical innovations. These factors both belong to the fourth component of the receptivity framework, application. Notably, all application factors are in the left half of the diagram. They are relatively unimportant according to the respondents. The results indicate that more priority should be given to improve association and acquisition rather than investing to improve application. A sensitivity analysis of the factors' 95% confidence interval was executed to analyze whether any of the factors could be situated in another quadrant. For none of the factors this was the case.

Table 9.4 Statistical differences ($P < 0.05$) in rating of importance and quality of key factors between subgroups (WB=Waterboard, MU=Municipality, TT=Transition Thinker, MT=Mainstream Thinker, HPE=Higher Professional Education, UE=University Education; SR>10 years experience, JR<10 years experience; IE=experience with innovations, NI= No experience with innovation)

Aspect	Receptivity Attribute	Factor	WB (n = 26)	MU (n = 46)
Importance	-	Achieving the National objectives in urban water management	8.3	7.4
Importance	Application	Financial incentives and subsidy schemes from national government	7.7	7.2
Importance	Association	Involvement of citizens in urban water projects	8.1	7.5
			IE (n = 42)	NI (n = 32)
Importance	Awareness	Water management knowledge of other stakeholders	7.4	8.0
Importance	Application	Commercial viability for private organisations of technical innovations	5.6	6.6
Importance	Application	Binding targets for water quantity and water quality	5.3	6.8
			TT (n = 7)	MT (n = 82)
Importance	Acquisition	Trust between cooperating partners in urban water projects	9.3	8.4
Quality	Association	Availability of a national overarching vision for urban water management	5.3	6.0
Quality	Awareness	Juridical and administrative knowledge in urban water management	6.8	5.4
			SR (n = 36)	JR (n = 53)
Quality	Application	Financial incentives and subsidy schemes from national government	4.1	5.3

9.3.5 Statistical differences

The survey allowed testing differences within the professional community. There were only limited statistical significant differences between subgroups as shown in Table 9.4.

In most cases the answers were consistent across groups. Type of organisation and experience with innovative technologies influence the perceived importance of some key factors. Professional experience and attitude towards transformative change affect the perceived quality differences of some key factors. Professional experience with innovative technologies results in a lower acknowledgement of the importance of some application and awareness key factors. A

remarkably high score (average=9.3) was ascribed to the key factor trust by transition thinkers. Although the group of transition thinkers was small (n=7) none of them gave a lower score than 8.0 to this factor. Professional experience influenced the perceived quality of financial incentives and subsidy schemes from national government.

9.4 Discussion

According to the professionals in this study, there is no need for large-scale implementation of new concepts to replace current urban water management infrastructure. Most respondents are convinced that the objectives of sustainable urban water management can be achieved by optimisation of the current water system. There is a lack of receptivity for transformative change. It is therefore not surprising that innovations that are not compatible with the current centralised systems, have failed to break through to mainstream practice. At the same time, the professionals are convinced that cooperation with other sectors is required to achieve the objectives of sustainable urban water management. In particular, strengthening the link between water management and urban renewal is seen as an important element. This finding corresponds to the results of Rotterdam case study in the previous chapter, the key conditions that were identified in chapter 7, and the broader national change in Dutch water management in which spatial planning, and water management become integrated (Van der Brugge et al., 2005).

The effect of climate change on urban water systems was regarded the most urgent problem. However, unexpectedly some related problems such as land subsidence and droughts were not at all mentioned. In the Netherlands, land subsidence is the most important factor contributing to the relative sea level rise, and the drought of 2003 dominated the news with items on salt intrusion and fresh water demand for flushing of polders. Moreover, a national enquiry on this topic was completed recently (Riza, 2005). It seems that professionals expect the national government to outline the main objectives. The provision of a general direction creates flexibility for professionals to adapt objectives to the local environmental, spatial and administrative conditions. The high priority given to improving knowledge of the local urban water system supports this finding. Binding targets for water quality and water quantity were considered least important. Although Australian research (Brown and Clarke, 2007) listed binding targets and private sector opportunities as key enabling factors for the transition in urban water management, the Dutch urban water management professionals in this survey are not convinced of the importance of these factors. This may be due to the fact that private sector involvement in Dutch urban water management is small compared to Australia.

Association factors and acquisition factors were considered most important to achieve the desired objectives in urban water management. Priority factors that should be addressed to achieve a more sustainable urban water system are improving knowledge of local urban water systems, experience in connecting water management and spatial planning, developing trust between stakeholders, support and commitment of elected officials to sustainable water management, and involvement of citizens in urban water projects. The first four were also mentioned as important success factors of Rotterdam Watercity 2035 in chapter 8. This finding shows a striking difference to the current government policy that is targeted at improving awareness and application factors. The realisation strategy of the National Waterplan (Ministerie van Verkeer en Waterstaat, 2008a) mainly consists of strengthening legislation, improving knowledge and increasing awareness. Improved cooperation is mentioned as key component as well. However, this is to be achieved by strengthening legislation and a river basin approach rather than improving association and acquisition of stakeholders. The Dutch findings are in line

with the results of the Australian survey that indicated serious acquisition factors that need to be addressed (Brown and Farrelly, 2007). The professionals in this survey wish to improve involvement of elected officials and citizens in urban water management. Generally, priority should be given to the association and acquisition factors to achieve sustainable urban water management. In addition, knowledge of the local water system should be improved.

9.5 Conclusion

Worldwide, the need for transformative change in urban water management is acknowledged by scientists and policy makers. The objective of this chapter was to gain insight in the potential for transformative change in the Dutch urban water management sector. The receptivity framework used in this research consists of four attributes; awareness, association, acquisition and application. The framework was applied to classify 20 key factors to provide empirical evidence regarding receptivity for transformative change in urban water management. These factors were derived from case study experiences in part 1 of this thesis and urban water management literature. Results in this chapter show that the receptivity to transformative change is low. Even in this survey group of policy experts with a good overview of current urban water management issues, there is no perceived necessity to radically change urban water management practice. The professionals are convinced that the societal objectives in urban water management can be achieved by optimisation of the current centralised urban water system. In addition, cooperation with other sectors is necessary and five key factors are regarded top priority to be further improved: 1) Available knowledge about the local urban water system, 2) Trust between cooperating partners in urban water projects, 3) Experience in connecting water management and spatial planning, 4) Support and commitment of elected officials to sustainable water management, and 5) Involvement of citizens in urban water projects. The first four were also mentioned as important success factors of Rotterdam Watercity 2035 in chapter 8. The respondents stress the importance of improving association and acquisition factors, in contrast to current government policy. The results of this study may therefore be helpful to policy makers to take into account professional perceptions in the development of national policy, in order to achieve better translation of policy to practice.

10 Perspectives on innovation: a survey of the Dutch urban water management sector¹⁰

10.1 Introduction

The literature review in the introduction section showed that reliable and well-documented decentralised stormwater management technologies and water recycling technologies are currently available to realise less vulnerable urban water management in practice. However, implementation remains limited to pilot projects and trophy systems (Brown, 2005; Hunt and Rogers, 2005). The chapters in part 1 of this thesis demonstrated the technical feasibility of a number of urban water management innovations. Chapter 7 identified stakeholder receptivity as one of the two key conditions to achieve mainstreaming of urban water management innovations. Chapter 9 showed that the receptivity of urban water management professionals to transform the current water system is low. Based on the same survey as chapter 9, this chapter specifically addresses the considerations of urban water professionals to choose an innovation. More specifically, their receptivity to the technical innovations from part 1 of this thesis will be evaluated. In addition, this chapter presents relations between experience, perceived level of knowledge, perceived contribution to sustainability, and expected timeframe for implementation.

10.2 Methodology

10.2.1 Framework

The receptivity framework of Jeffrey and Seaton (2003) was applied to analyze the professional perception on change in urban water management. This framework was described in chapter 7. Using the receptivity framework as a guiding model the following themes were addressed by this survey:

- Experience with urban water innovations (acquisition)
- Considerations to apply innovations (application)
- Perceived level of knowledge of urban water innovations (awareness, acquisition)
- Perceived contribution to sustainable urban water management (association)
- Expected implementation timeframe (application)

10.2.2 Study focus

This study intended to examine professional perspectives on the application of innovative technologies in urban water management. Two sets of technologies were applied. The first set was defined by the respondents themselves. Respondents were asked whether they had implemented innovative technologies in the last three years. No definition of an innovative technology was given. The results therefore reflect the perception of technologies that respondents consider innovative. This approach ensured that the outcomes correspond to professional perceptions rather than a scientifically based definition. The respondents had to specify which technologies they had gained experience with. In addition, they had to assess the importance of a selected set of considerations that led to application of the technology. The considerations of respondents were measured using a rating scale with 11 response options,

¹⁰ This chapter is based on: De Graaf, R.E., R.J. Dahm, J. Icke, R.W. Goetgeluk, S.J.T. Jansen and F.H.M. van de Ven. Perspectives on innovation: a survey of the Dutch urban water sector (*submitted to Urban Water*)

anchored by *not important at all* on the left side and *extremely important* on the right side. The considerations were based on previous research on stakeholder perceptions in urban water management (Brown and Farrelly, 2007) and literature on decision support systems in urban water management (Ashley et al., 2004). The considerations were adapted to Dutch circumstances through expert consultation in the Transitions SUW project. Table 10.1 presents the twelve considerations that were studied in this survey. The second set of innovative technologies contained five predefined technologies. Three of them were derived from case studies of the Dutch Transitions-SUW project. The technologies used in this project are: alternative local sources for residential water supply (chapter 4), using the local urban water system as energy source (chapter 5) and floating urbanisation (chapter 6). Two additional technologies were added because they are often mentioned as sustainable options among professionals in the Netherlands, these are: local stormwater retention (Beenen and Boogaard, 2007) and decentralised sanitation and reuse (Lens, Zeeman and Lettinga, 2001). To provide an example to the respondents the innovative technologies were specified with several applications of the innovative technology. Table 10.2 shows the specification of each technology with several applications to provide an example to the respondents.

The perceived knowledge level for each innovative technology was tested. Five answering categories were precoded ranging from *'never heard of'* to *'expert in this field'*. The respondents were also asked to rate the perceived potential contribution to sustainable water management of these predefined innovative technologies on an 11-point rating scale, anchored by *extremely poor* on the left side and *excellent* on the right side. The questionnaire also investigated the expected implementation timeframe of these technologies in the administrative area of the respondents' organisation.

Table 10.1 Considerations for the application of innovative technologies that were tested in this survey

Social considerations	Economic considerations	Ecological considerations	Technical considerations
Effects on spatial planning	Investment costs	Environmental impacts	Inadequacy of conventional technology
Acceptability to citizens	Operational costs		Organisational experience with innovative technologies
Effects on public relations	Availability of financial incentives and subsidy schemes		Expected implementation timeframe
Public health impacts			Reliability of technology

Table 10.2 Some illustrative applications of the innovative technologies

Innovative technology	Applications
Water retention	Green roofs
	Water retention square
	Infiltration facilities
Decentralised sanitation and reuse	Separate collection of urine and other wastewater stream
Source of energy	Aquifer Thermal Energy Storage (ATES)
	Local surface water as energy source
Alternative sources of water supply	Rainwater and stormwater
	Local surface water
	Local groundwater
Floating urbanisation	-

10.2.3 Survey and analysis

The group was the same as described in chapter 9. Subgroups were used to enable testing of significant differences in the practitioner receptivity to innovations based on these characteristics.

T-tests were executed to find differences in numerical variables based on subgroups. To find significant differences in the knowledge level of innovations based on subgroups, Mann-Whitney U test were executed. This is a nonparametric test to find an association between unrelated subgroups and ordinal data. To find significant subgroup differences in the expected implementation time, chi-square tests were used. The chi-square test was more appropriate for this variable, because the categories of implementation time can not completely be regarded as a ranking order. Finally, chi-square tests were done to find the association between experience, knowledge level, and perceived contribution to sustainable urban water management, and expected implementation timeframes. Also in this chapter, respondents, who are convinced that the present urban water system should be replaced with new concepts and technologies to achieve sustainable urban water management, are referred to as transition thinkers. Their perception was examined and compared with mainstream thinkers. The case by case method of dealing with missing values was applied in this research. Thus, all valid answers to individual questions were taken into account in the results that are presented.

10.3 Results

10.3.1 Experience with innovations

Nowadays there is a wide interest in the application of innovative technologies in the urban water sector. The results from the questionnaire show that 57% (n=42) of the respondents have been involved in urban water projects in which an innovative technology was applied in the last three years; 2005 - 2008. The largest group (40%; n=17) has gained experience with local water retention. The remaining respondents have experience with a variety of innovative technologies, such as water as source of energy (5%), alternative sources of water supply (5%), operational sewage management (5%), surface water retention (8%), innovative dredging (5%), management of interactions between urban and rural water management (5%) and other technologies.

10.3.2 Considerations to apply innovative technologies

The 42 respondents who have gained experience with innovations were asked to rate the importance of twelve considerations in the decision making process that led to application of the innovative technology. The mean results seem to show a partitioning into three levels of importance (see Table 10.3): i) one group of four considerations that have the most importance, ii) one group of six considerations showing moderate importance and iii) one group of two considerations showing the least importance. Most important considerations to the respondents are: the reliability of a technology, the effects on spatial planning, environmental impacts and investment costs. Least important are public health impacts and the availability of subsidies.

Table 10.3 Considerations to choose innovative technologies to achieve sustainable urban water management

Considerations	Mean (n=42)	St. Dev
Reliability of innovative technology	7.1	0.31
Effects on spatial planning	7.1	0.34
Environmental impacts	7.0	0.38
Investment costs	7.0	0.30
Inadequacy of conventional technology	6.5	0.39
Acceptability to citizens	6.3	0.33
Operational costs	6.3	0.30
Effects on public relations	6.3	0.29
Organisational experience with innovative technologies	6.3	0.34
Expected implementation timeframe	6.1	0.32
Public health impacts	5.3	0.33
Availability of financial incentives and subsidy schemes	5.1	0.43

Table 10.4 shows the statistical significant differences between subgroups. In general, not many significant differences were observed. Type of organisation seems an important factor for financial incentives. For respondents employed at waterboards, this consideration is significantly less important than for respondents working at municipalities. This may be explained by the fact that in the Netherlands, waterboards are eligible to collect taxes for water management. Municipalities on the other hand, have to make a political deliberation to spend funds on water management or other themes. Attitude towards transformative change influenced the rating of three considerations. Even though the group of transition thinkers was small, three statistically significant differences were found. In all of these cases, transition thinkers gave a higher importance rating (see Table 10.4).

As defined in this survey, transition thinkers believe that current urban water systems should be completely replaced by new concepts and new technologies. Presumably, they believe that reliable technologies that organisations have experience with should be applied to achieve this purpose. In addition, this group regards connection to spatial planning and organisational experience as key considerations to choose an innovative technology. The relatively low standard deviation is an indication for a high level of consensus among transition thinkers with regard to these factors. Finally, investment costs were more important to respondents with a higher

professional education compared to respondents with a university degree. The former group may be more focused on practical considerations such as costs in comparison to the potentially more theoretical approach of the respondents with university education.

Table 10.4 Statistical differences ($P < 0.05$) of importance of considerations (scale 0-10) to choose innovative technologies according to subgroups (WB=Waterboard, MU=Municipality, TT=Transition Thinker, MT=Mainstream Thinker, HPE=Higher Professional Education, UE=University Education)

Considerations	WB (n=12)	Std Dev	MU (n=19)	Std Dev
	Availability of financial incentives, subsidy schemes	3.9	2.50	6.1
	TT (n=5)	Std Dev	MT (n=36)	Std Dev
Reliability of innovative technology	8.4	0.55	6.9	2.06
Effects on spatial planning	9.2	0.84	6.7	2.40
Organisational experience with innovative technologies	7.4	0.90	6.1	2.20
	HPE (n=24)	Std Dev	UE (n=15)	Std Dev
Investment costs	7.9	1.50	6.3	1.9

10.3.3 Perceived knowledge level of predefined technologies

All respondents were asked to answer questions with regard to their knowledge of the five predefined innovative technologies, including those respondents without recent experience with innovations. Five answering categories were provided: *'never heard of'*, *'heard of, but not familiar'*, *'reasonably familiar'*, *'well-known'*, or *'expert in this field'*. The respondents are aware of the innovative technologies. For all technologies, less than 10% of the respondents had never heard of this specific technology. However, this familiarity did not correspond to a high knowledge level. Table 10.5 shows the aggregated results in which *'well-known'*, or *'expert in this field'* are combined to the category *'high knowledge level'* and the other categories to *'low knowledge level'*. Water retention is the only technology with a high proportion in the high knowledge level category.

Significant differences between subgroups and the original five knowledge level categories were found based on Mann-Whitney U tests. Respondents with experience in applying innovative technologies have more knowledge of water retention ($p=0.0030$) and urban water system as energy source ($p=0.030$) than those who do not have this experience. In addition, respondents with university education have better knowledge of water retention ($p=0.012$), the use of the urban water system as energy source ($p=0.010$) and the use of alternative water sources ($p=0.024$) compared to respondents with higher professional education.

Table 10.5 Knowledge level of innovative technologies among subgroups, bold font is used for statistically significant subgroup differences. (WB=Waterboard, MU=Municipality, TT=Transition Thinker, MT=Mainstream Thinker, HPE=Higher Professional Education, UE=University Education)

Innovative technology	Classification	General (n=71)	Employer		Experience in profession		Experience with innovations		Attitude towards change		Level of education	
			WB (n=37)	MU (n=21)	<10 years (n=42)	> 10 years (n=29)	Yes (n=40)	No (n=31)	TT (n=6)	MT (n=65)	HPE (n=33)	UE (n=37)
Knowledge Level		%	%	%	%	%	%	%	%	%	%	%
Water retention	Low	28	29	29	33	20	15	44	17	29	46	14
	High	72	71	71	67	80	85	56	83	71	54	86
Decentralised sanitation and reuse	Low	65	67	62	67	62	59	72	67	65	62	68
	High	35	33	38	33	38	41	28	33	35	38	32
Urban water system as a source of energy	Low	75	86	76	79	70	68	84	50	77	82	68
	High	25	14	24	21	30	32	16	50	23	18	32
Alternative sources of water supply	Low	57	62	60	71	37	48	69	67	56	70	46
	High	43	38	39	29	63	52	31	33	44	30	54
Floating urbanisation	Low	71	76	74	77	63	68	75	50	73	78	62
	High	29	24	26	24	37	32	25	50	27	21	38

Senior respondents have a higher knowledge level of one technology: alternative sources of water supply ($p=0.005$). This could be explained by the fact that constructing a third pipe system was prohibited by the national government in 2003 after the Leidsche Rijn incident, for more information see chapter 4. Since the prohibition, the debate on alternative water sources in urban water management has almost ceased in the Netherlands. Consequently, junior employees may not have been exposed to knowledge of alternative water sources and are therefore less familiar with this technology.

Notably, most respondents who qualify themselves as *'well known'* or *'expert in this field'* were not recently involved in projects in which the specific technology was applied. According to them, a high level of knowledge can be achieved without having experience with this specific technology. Instead, a high level of knowledge can be obtained by internalisation of explicit knowledge. This suggests a high appreciation of theoretical knowledge rather than experiential or practical knowledge. It may also suggest a distance or disconnectedness to practice of this

professional community working on policy issues. Table 10.6 shows that about one third of the respondents, who consider themselves as *'well known'* or *'expert in the field'*, have not at all been involved in a project which utilised innovative technologies

Table 10.6 Cross tabulation of experience and knowledge level of respondents who classified their knowledge level as *'well known'* or *'expert in the field'*.

Innovative technology	High perceived knowledge level of a specific technology	Recent experience with this specific technology	Recent experience with other technologies	No recent experience with innovative technologies
Water retention	n=52	30.7%	34.6 %	34.6%
Decentralised sanitation	n=25	0%	64.0 %	36.0 %
Water system as a source of energy	n=18	5.6%	66.7 %	27.8 %
Alternative sources of water supply	n=31	6.5%	61.3 %	32.3 %
Floating urbanisation	n=21	0%	52.0 %	38.0 %

10.3.4 Potential contribution to sustainable water management

The respondents were asked to value the perceived potential contribution of innovative technologies to achieve sustainable urban water management. Local stormwater retention was given the highest rating; 7.6 on an 11-point scale (ranging from 0 to 10), thus showing the respondents' confidence in this technology to contribute to sustainability. A moderate to high appreciation was given to alternative local sources for residential water supply (7.0). A moderate rating (6.6) was given to the use of the local urban surface water as energy source. Two technologies were considered to have the lowest potential contribution: floating urbanisation and decentralised sanitation and reuse with an average of 6.3, respectively 6.2. A possible explanation might be that these are the two technologies that the respondents have no experience with. The technology that most respondents have experience with was rated highest. However, no significant differences were found between the subgroups.

10.3.5 Expected implementation period

This part of the survey intended to develop insight into the expected implementation period of innovative technologies. Questions focused on application of the innovations in the administrative area of the respondents' employer, for instance in a pilot project.

Table 10.7 Perceived implementation period of innovative technologies among subgroups, bold font is used for statistically significant subgroup differences. (WB=Waterboard, MU=Municipality, TT=Transition Thinker, MT=Mainstream Thinker, HPE=Higher Professional Education, UE=University Education)

Classification		General (n=71)	Employer		Experience in profession		Experience with innovations		Attitude towards change		Level of education	
			WB (n=37)	MU (n=21)	<10 years (n=42)	>10 years (n=29)	Yes (n=40)	No (n=31)	TT (n=6)	MT (n=65)	HPE (n=32)	UE (n=37)
		%	%	%	%	%	%	%	%	%	%	%
Water retention	Already implemented	62	71	60	62	62	75	45	83	60	53	68
	Near future	24	29	24	24	24	13	39	17	25	28	22
	Future	6	0	8	2	10	5	7	0	6	6	5
	No expectation	9	0	8	12	3	6	10	0	9	13	5
De-centralised sanitation and reuse	Already implemented	19	34	11	21	14	18	19	50	16	19	19
	Near future	29	38	21	26	32	26	32	17	30	32	24
	Future	29	14	38	26	32	33	23	33	28	32	24
	No expectation	24	14	30	26	21	23	26	0	27	16	32
Urban water system as a source of energy	Already implemented	30	30	24	24	38	40	16	50	28	16	41
	Near future	37	35	52	36	38	30	45	33	37	41	32
	Future	21	19	19	24	17	25	16	17	22	31	14
	No expectation	13	16	5	17	7	5	23	0	14	13	14
Alternative sources of water supply	Already implemented	21	14	11	17	28	28	13	17	22	16	41
	Near future	35	43	27	38	31	33	39	50	34	40	32
	Future	24	29	32	21	28	23	26	33	23	31	14
	No expectation	20	14	30	24	14	17	23	0	22	13	14
Floating urbanisation	Already implemented	17	29	16	12	24	20	13	33	15	19	16
	Near future	30	38	35	29	30	35	23	67	26	28	32
	Future	28	24	24	31	28	18	42	0	31	28	27
	No expectation	25	9	24	29	25	28	23	0	28	25	24

Table 10.7 shows that all innovative technologies have already been implemented in at least some areas. The near future was defined as application within the next five years. Floating urbanisation is least common. Local stormwater retention is the most widespread innovation. Chi-square tests provided two significant statistical differences. Waterboards have a higher expectation of decentralised sanitation compared to municipalities ($p=0.033$). Respondents with recent professional experience with innovative technologies are more positive about the implementation period of the water system as energy source ($p=0.025$). Although transition thinkers seem more positive about the implementation of innovations than mainstream thinkers, the size of this group did not allow for significant differences to be found. For local stormwater retention ($p=0.053$), the use of the local urban water system as energy source ($p=0.025$) there is a significant correspondence between experience with innovation and the expected implementation period. Respondents with experience expect faster application than those without this experience. Most innovative technologies show a significant correlation between the perceived knowledge level and expected implementation period. For water retention the chi-square test could not be executed because the number of respondents who do not expect application of this technology is insufficient. Results are presented in table 10.8.

Table 10.8 Significant correlations from chi-square tests between knowledge level of technologies and expected implementation period

Innovative technology	Value	Chi-square significance level p
Water retention	n/a	n/a
Decentralised sanitation	7.060	0.070
Water system as a source of energy	12.01	0.070
Alternative sources of water supply	16.04	0.001
Floating urbanisation	7.97	0.047

10.4 Discussion

The respondents in this survey are well aware of the innovative options that are available in current urban water management. Most of them have heard of the innovations that were studied in this thesis. The first component of the receptivity framework, awareness, seems well developed. The application component of the receptivity framework also seems well developed. The respondents predominantly foresee application of these technologies in the administrative area of their current employer within five years. Similar to the results in chapter 9, this suggests that awareness and application are not a priority that should be addressed by national water management policy.

Despite having positive expectations, the respondents generally have a low knowledge level of the surveyed technologies, with the exception of local water retention. A negative relationship between knowledge level and expected implementation time was found. Thus, improved knowledge of innovations could further decrease the expected implementation time. This is important since expectations in a professional community is a factor that can enable, shape or prevent further development of a specific technology (Van Lente and Rip, 1998). Capacity building by improving the knowledge could therefore contribute to mainstreaming of these innovations.

The respondents had a moderate appreciation of the potential sustainability contribution of the technologies. The second component of the receptivity framework, association, indicates barriers to further diffusion of the technologies. The exception is local stormwater retention which received a high rating. Technologies that improve water quality, such as decentralised sanitation, and technologies that decrease fossil fuel dependency, such as using the local urban surface water as energy source, received moderate ratings. A possible explanation is the lack of experience respondents have with these technologies. Although the respondents expect rapid implementation, they are not convinced that the technologies will have significant contribution to a more sustainable urban water system. Probably they expect small scale implementation which would correspond to the results in chapter 9 that transformation of the current urban water system is not considered necessary.

With the exception of local stormwater retention, the personal experience level with innovative technologies in urban water management was low. However, the respondents do not see professional experience as an essential condition to achieve a high level of knowledge. The majority of the respondents, that gave a high qualification to their own knowledge level for a specific technology, had no experience with this technology over the past three years.

A possible explanation might be that the professionals prefer explicit knowledge above tacit knowledge. Explicit knowledge is knowledge in the form of books, guidelines and report whereas tacit knowledge is personally bound and gained by personal experience in practice. Nonaka and Takeuchi (1995) found that western organisations are often more focused on explicit knowledge rather than tacit knowledge. However, in the same book, the authors demonstrate that both types of knowledge are essential in innovation processes. Explicit knowledge is needed to be able to apply most recent technologies and distribute knowledge. Tacit knowledge is essential when the step from vision to implementation is to be made. The lack of experience with innovations and the lack of appreciation of tacit knowledge can therefore be an obstacle to innovation in the urban water management sector.

The results suggest a disconnection between the policy making and strategy community and the implementation and construction community. In the case study in Rotterdam (chapter 8), the distance between these two communities was also mentioned as a transition barrier. The results indicate that developing experience is necessary to advance innovations in urban water management. The respondents who had recent professional experience with innovative technologies showed a more positive attitude towards the expected implementation timeframe for two technologies. Possible measures to enhance the receptivity of professionals should therefore include increasing the exposure of professionals to innovative practice to strengthen tacit knowledge. However, this will only be attractive to career driven professionals if experiential knowledge is appreciated and included in reward mechanisms of organisations. Demonstration projects should be started in order to build more experience with these technologies. This is in correspondence with the observation of Brown et al., (2009) who listed well-designed demonstration projects as a way to improve receptivity of professionals. Demonstration projects can also contribute to improving the reliability of technologies, which in this survey appeared to be one of the most important considerations for application. Demonstration projects should be combined with capacity building programs, evaluation and monitoring to allow for improvement and replication of these technologies on a wider scale. Without this condition, the application of innovative technologies will remain limited to showcases and demonstration projects, with no significant impact on mainstreaming of innovations to improve the overall performance of urban water management.

Notably, none of the considerations for application of innovations in urban water management received a high rating. Perhaps, the twelve pre-defined considerations do not cover the whole range. Follow up research is necessary to obtain improved insight into the considerations to apply innovative solutions in practice. Transition thinkers in the survey regard reliability of new technologies, organisational experience, and effects on spatial planning as key considerations to apply new technologies. This small group has a strong internal consensus on the importance of these factors. Recent research on water management transitions (Van der Brugge et al., 2005; Brown et al., 2009) and the Rotterdam case study in this thesis also suggest that these factors are essential. The strongly differing opinion of the transition thinkers compared to mainstream thinkers is remarkable. Limitations of the research results are found in the small group size. However, the results suggest a strongly differing opinion of this subgroup. This should be investigated in more detail in follow up research to allow for more general conclusions.

Our current urban water systems have been successful in dealing with public health problems (Butler and Parkinson, 1997). However, for applying new technologies, public health impact was considered unimportant. It seems that one of the main functions of urban water management and sewer systems (Larsen and Gujer, 1997) is not an issue when implementing innovative technologies. A possible explanation could be that the respondents feel that major public health problems are already solved, and consequently, they do not focus on the health impact of new technologies.

10.5 Conclusion

In chapter 7, stakeholder receptivity to innovative technologies is a key condition to further advance sustainable urban water management. The study addressed five themes; experience with innovations in general, considerations to apply innovations, current knowledge level, perceived contribution to sustainability, and expected implementation timeframe. The objective of this chapter was to gain insight in the receptivity of professionals in the Dutch urban water management sector to the innovative technologies that were presented in part 1 of this thesis. The results showed that the respondents are well aware of the technical innovations and that they expect application in the near future. However, in general their experience with innovations is low.

Most respondents that had a high knowledge level of a specific innovation had not been recently involved in projects in which this innovation was applied. Moreover, the respondents have a moderate appreciation of the potential contribution of these technologies to sustainable urban water management. This suggests that the respondents expect that the innovations will be applied, yet they will remain isolated in small scale projects with limited impact on the overall system. The results therefore reflect significant obstacles to mainstreaming of innovations for sustainable urban water management. Professionals are not yet convinced that innovations are essential to achieve the objectives in urban water management. For most of the technologies their level of knowledge is low. They are not convinced that personal experience in the practical application and further development of these innovations is required to achieve a high knowledge level. The distance between the policy making community and the implementation community is large. It is therefore recommended that future reform interventions to transition to more sustainable urban water management are more targeted at improving association and acquisition factors of the receptivity framework and reduce the distance between policy and implementation by involving policy makers in the implementation phase.

11 Discussion and conclusions for mainstreaming of urban water management innovations to reduce vulnerability

11.1 Introduction

The first objective of this thesis was to demonstrate the technical feasibility of urban water management innovations to reduce vulnerability of urban areas. In addition, the objective was to develop insight in the feasibility of these innovations in case studies. The final objective was to study how urban water management innovations can be adopted in mainstream urban water management practice. In the introduction of this thesis the following research questions were presented:

- A) Vulnerability
 1. What is a useful framework to understand water related vulnerability of urban areas?
 2. What can we learn from other countries in dealing with water related vulnerability?

- B) Innovations in urban water management
 1. How could innovations in urban water management be used to reduce vulnerability of urban areas?
 2. What is the feasibility of these innovations in practical case studies?

- C) Governance mechanisms
 1. What mechanisms can be identified that influence mainstreaming of innovative concepts in urban water management?
 2. What is the practitioner receptivity to changes in urban water management and application of innovative concepts?
 3. What would be useful strategies and recommendations to achieve mainstreaming of innovations in urban water management to contribute to cities that are less vulnerable?

11.2 Vulnerability

11.2.1 Framework and application

Vulnerability is often defined as the sensitivity of a system to exposure to shocks, stresses and disturbances, or the degree to which a system is susceptible to adverse effects. Climate change, resource scarcity and the continuing rapid urbanisation of low lying deltas are increasing the vulnerability of cities. Currently, cities completely depend on external areas for their resources. Internal resources that are available, such as local water and energy sources, are hardly used. Urbanisation is increasing the pressure of cities on their surroundings. This is a reason for cities to make better use of internal resources. Large scale centralised infrastructures to supply water and energy resources are considered to be efficient. These infrastructures generally supply water and energy to cities in a reliable way against low costs per capita. However, they are not optimal for using local resources, and they make cities vulnerable during disruptions. Moreover, large scale infrastructures have a low capacity to adapt to uncertain future development due to sunk

costs, vested interests and social and technical lock in patterns. Consequently, in order to reduce vulnerability, cities will have to make better use of local resources. This thesis presented how urban water innovations can be used for this purpose.

Chapter 2 described that the vulnerability of an urban area is determined by four capacities. Threshold capacity is the ability of a society to build up a threshold against variation in the environment in order to prevent damage. Coping capacity is the capacity to reduce damage in case of a disturbance that exceeds the damage threshold. The third component, recovery capacity refers to the capacity to recover to the same or an equivalent state as before the disaster. Finally, adaptive capacity is the capacity of a society to anticipate on uncertain future developments. This includes catastrophic, not frequently occurring disturbances like extreme floods and severe droughts. The vulnerability framework shows that vulnerability capacities are highly connected. Higher dikes could result in increased investments, decreased risk awareness and decreased experience in dealing with the impacts of floods. Increasing one capacity possibly results in higher, rather than reduced vulnerability.

Including all four capacities of the vulnerability framework enables better understanding of water and climate related vulnerability of urban areas. Moreover, the framework can assist in developing more complete water management strategies to reduce vulnerability. Based on this framework it can be concluded that in the Netherlands, current strategies for water supply and flood control management mainly focus on the first capacity of vulnerability by increasing threshold capacity. The current water management system is optimised with the objective of reducing the risk. This optimisation includes damage prevention by higher dikes, increased discharge capacity of rivers, and more efficient large scale water supply infrastructure. However, absolute security is both theoretically unattainable and practically unaffordable. Therefore, there will always be occasions where coping with floods and droughts and recovering from them is necessary. Central to the importance of adaptive capacity is the acknowledgement that urbanisation and climate change may be influenced but cannot be predicted and controlled. Therefore, it is essential to develop the capacity to adapt urban water management to these uncertain future developments. Consequently, developing comprehensive strategies that develop all four capacities of the vulnerability framework is essential.

By using local resources in addition to external resources, coping capacity can be improved. During droughts, urban districts do not depend on one single external source. Instead, they use a combination of local stormwater, river water, recycled effluent and regional surface water. Recovery capacity can be enhanced by emergency plans and backup facilities such as water trucks. Backup water supply points in each city also reduce damage and secure water supply for the population during disasters. If local resources can be used to produce good quality drinking water, recovery to a normal water supply condition takes place more quickly as cities do not depend on external water resources only. Two strategies were mentioned in chapter 2 that contribute to improving the adaptive capacity of water supply: experimenting with other modes of water supply to build diversity of water sources, and flexible and reversible water supply infrastructure to be better prepared for future uncertainties.

Timely flood warning and improving risk communication make residents better prepared to cope with flooding. The current potential for evacuation in the Netherlands is limited; however, this could be different in the future if there would be more local shelter, a flood proof urban environment and emergency refuge areas. Improving recovery capacity from urban flooding can be done by insuring flood risks and disaster funds. The availability of recovery equipment and recovery plans also contribute to this capacity. There are three main components of an adaptive

flood control strategy: building diversity by experimenting with multiple innovations, flexible and reversible infrastructure, and reservation of space by integration of water management and spatial planning.

11.2.2 Examples from Japan

Water management in Japan is in particular interesting with regard to climate adaptation. This country already has an extreme climate. Moreover, similar to the Netherlands, it is a highly urbanized, industrial country with a high percentage of invested capital and population in flood prone areas, including areas under sea level. Thus, the systems that are in place in Japan can provide us with ideas how Dutch urban water systems could function in the future. Japan is a country that is frequently exposed to all kinds of natural hazards including flooding and droughts. Consequently, coping and recovery capacity are relatively well-developed in Japan. The adaptive capacity is partly developed. A wide diversity of technologies is available to adapt to changes in the physical conditions. However, also in Japan the flexibility of the main urban water management infrastructure is low. Based on the vulnerability analysis, it can be concluded that in Japan all four capacities of the framework are used to reduce vulnerability of urban lowland areas.

For urban pluvial flood control, not only improving sewer capacity is applied but also risk communication, stakeholder involvement, emergency plans, wet proofing of buildings and elevated houses and infrastructure. Other coping and recovery capacity increasing capacity measures that reduce the effects of flooding are stormwater infiltration and retention and securing access to flooded areas by elevated roads and emergency ship locks.

Tokyo's water supply does not only focus on better and more efficient water storage and delivery infrastructure but also on demand management, water recycling, water saving technology and decentralised, more flexible water supply. A range of urban water resources is used for the water supply of cities like Tokyo, including stormwater and recycled wastewater. In particular recycled waste water is used for a whole range of urban water use functions. The use of recycled wastewater reduces drinking water demand and decreases the dependence of the city on external river water resources. In addition, emergency water supply system has been installed to be able to cope with droughts and other disasters that may disturb the main water supply system.

To better adapt to future water shortages and floods, demonstration projects with new modes of water supply and flood proof urbanisation are executed. New technical options are developed for the future. Examples are the experimental sewer system (ESS) and demonstration projects with multiple urban water sources such as stormwater, recycled water and wastewater effluent. One of the key elements of the Japanese adaptive strategy is experimenting with a variety of technical, institutional and social measures. This provides a society with a wide range of possibilities to anticipate on uncertain future developments. The Japan example provided a broad overview of possible options to reduce vulnerability by innovations in urban water management that contribute to more vulnerability components than threshold capacity only.

11.3 Innovations in urban water management to reduce vulnerability

The vulnerability framework demonstrated that using local resources in addition to external resources is needed to make cities less vulnerable. It also showed that current strategies in water management focus on improving threshold capacity by optimisation of the current system. One of the main objectives of this research was to study the feasibility of using the local urban surface

water and urban groundwater for new functions. Three technical concepts were presented in chapters 4-6.

11.3.1 Use of local water resources

The use of local water resources can contribute to reduce the vulnerability of urban areas. During droughts or disruptions of supply, urban areas no longer depend on one external source. Instead, a portfolio of water resources is used that enables coping with droughts and recovery from them. Climate change will lead to more frequent droughts. Because climate change effects are still uncertain, having a diversity of water sources is an adaptive strategy to make cities more self-supporting and flexible. Moreover, cities that make better use of their internal resources reduce the pressure on the surrounding areas. Using local water resources contributes to a number of attributes of future water systems that were summarised in chapter 1. It can contribute to pluvial flood control by local water retention. Utilizing local water resources decreases the extraction of water in nature reserves and reduces the output of stormwater and wastewater effluent to the surroundings. Hence, stormwater and wastewater impacts are reduced and aquatic ecosystems are protected. The surface water is used for the new function of local drinking water production. Moreover, it is a decentralised solution that is more flexible and adaptable compared to large scale infrastructure. If local urban surface water is used for water supply, there is also a strong incentive to control water quality in urban areas.

Results for De Draai Heerhugowaard showed that an entirely self-supporting urban water supply is not feasible. However, even in a dry year such as 2003, less than 5% external supply is required on a yearly basis. New urban developments can therefore be much more self-supporting. Water quality analysis and proposed treatment schemes showed that it is technically possible to produce drinking water from local resources. The expected costs were low although substantially higher than connecting the district to the conventional system.

The reliability, expressed in expected minutes of insufficient supply per house per year, is expected to be lower in a decentralised system than in a conventional system. However, this conceptualisation of reliability does not take into account the possible simultaneous failure of water supply to all houses in a region (system risk). It is this property of centralised systems, although 'reliable', that makes society vulnerable to large scale disruption.

Rainwater harvesting appeared to be a promising technology in this project. The expected drinking water demand reduction was up to 27% on a yearly base. Following this project, rainwater harvesting is still in the process to be included in the development plans of the municipality on a pilot scale.

Based on experiences in this project, there are three most important obstacles to utilisation of local water resources in the Netherlands. The first is the restrictive national government health policy. The second is the lack of willingness of the water utility sector to use local water resources. Apart from rainwater harvesting projects, the technical water utility community is not convinced of the benefits of developing local water resources. The third is the lack of involvement of other stakeholders in decision making processes concerning the future of urban water supply. There is a trade-off between having an efficient, centralised system that is vulnerable to rarely occurring, large scale disruptions, and a local, less efficient system that has a lower overall vulnerability. Another option could be a mixture of both systems. Currently, the trade-off between these options is not made. The decisions are made by the technical water utility expert community with hardly any form of public deliberation. However, there is no democratic justification that the possession of knowledge of a complicated system should give experts the right to make decisions

on the future functioning of an essential system to society. In particular, they have no such rights because their interests and positions depend on the continuing functioning of the present system. At present, stakeholders are ill equipped to fulfil a more active role in water supply due to the fact that they have been passive consumers for more than a century. Therefore, other stakeholders are probably not yet able or willing to participate in these processes. Given the importance of the functioning and future of urban water supply, they should become more involved and they should be trained to be able to participate. The position of the expert would then change more from the current deciding role towards a source of reliable knowledge in a participatory process.

Contrary to the water utility sector, the results of the national urban water management survey showed that employees of waterboards and municipalities were rather positive about using local water resources. A moderate to high appreciation was given to alternative local sources for residential water supply (7.0) for the potential contribution to sustainable urban water management. This was the second rank of the five technologies that were tested. More than half of the respondents thought that this concept was already implemented or would be implemented within five years. Probably the respondents had local rainwater harvesting in mind, as this was one of the examples given in the questionnaire.

Despite the positive expectation of waterboards and municipal employees, there is no reason to expect that local water resources will be used in the Netherlands on a wider scale in the near future. The receptivity in the water utility sector for local water supply is low. This is understandable, because there is no perceived sense of urgency of water scarcity. Furthermore, local water resources can be regarded as a competitor for centralised systems. The fixed costs of the centralised network will have to be recovered from a smaller base of users if districts start developing their own local water supply systems. If competitors start to offer local water supply technologies to municipalities, there may be an incentive for water utilities to enter this market. At this moment, however, there is no competition. At meso level, public health concerns and restrictive policy are barriers for the application of this concept. Unless other stakeholders that are more positive, will be involved in decision making processes, unless competitors enter the market, and unless the societal demand for more local scale solutions increases, the most likely course of water supply will be further optimisation of the centralised system and increase of scale.

11.3.2 Use of the local urban water system as an energy source

Chapter 5 demonstrated that De Draai in Heerhugowaard can be self reliant for heating and cooling purposes by applying Aquifer Thermal Energy Storage supplemented with surface water heat collection (ATES+). The district does not need to rely on international gas distribution networks that might be disrupted in the future by geopolitical tensions, incidents or terrorism. Price fluctuations on the international energy market have only a small impact on the heat and cooling system of De Draai. Local energy supply can be regarded as an adaptive strategy to the uncertainties of the global energy market. The vulnerability of this district is lower than in case of a conventional system. Using this concept contributes to various attributes of future water systems that were summarised in chapter 1. It is a way of multifunctional use of urban water systems and a local source of energy that is more flexible and adaptable than large scale systems.

By cooling the surface water with 1.5-1.6 °C in three summer months, enough heat is collected to compensate the entire residential heating and cooling demand. With the concept of ATES+, fossil fuels are no longer required to produce heat for indoor climate control. Heat from the urban surface water and urban groundwater is used for this purpose. Electricity is still needed

to operate the system, however only for the transportation of heat instead of the production and transportation.

Considerable energy savings and a CO₂ emission reduction of 60% can be achieved. Water quality and ecological improvement take place because a lower temperature results in a higher oxygen content. The expected water temperature increase due to climate change can be partially prevented by applying this system. A net surface water temperature decrease in summer takes place. The concept is also economically feasible. The concept is more profitable than a conventional system if the full lifetime, all investments, and exploitation costs are taken into account. The viable business case shows that higher investments can be earned back by public or private exploitation of the system.

Climate change, energy scarcity and environmental awareness were important drivers to execute this study. The long existing ambition of the municipality Heerhugowaard to become the first CO₂ neutral municipality in the Netherlands created a window of opportunity. In addition, the municipality already had experience with another innovative urban development, Sun City, which was in the final stage of development during this study. At project level, a visionary and enthusiastic project leader who was open to new concepts was an enabling factor. Also the high percentage of surface water in De Draai was an incentive to study the economic potential of new functions of the urban surface water and urban groundwater. Without new economic functions, the high proportion of surface water would have remained an item of loss on the financial balance sheet of this urban development. As a consequence, the technical concept has been included in the official urban development process and will be applied in about 2800 houses.

The receptivity to this concept was reflected in the results of the national survey. Two third of the respondents thought this concept had already been implemented by their organisation, or will be implemented within five years. However, the personal experience and knowledge level for this specific technology were low. Results showed that respondents of waterboards and municipalities gave this concept a moderate rating (6.6) for the potential contribution to sustainable urban water management.

11.3.3 Using the surface water for urbanisation

An increasing number of floating urbanisation projects in the Netherlands and abroad demonstrate the technical feasibility. However, most of these projects are still small scale and located along the edges of lakes and rivers. These small scale settlements are still completely dependent on land based infrastructure. Technical obstacles are related to the connection with utilities, accessibility from the mainland, and creating public space on the water.

Floating urbanisation has the potential to contribute to reduce vulnerability of delta areas. During floods it may contribute to coping capacity. Floating houses will adapt to the rising water level and they potentially function as emergency shelter during flooding. Because floating houses can be relocated, they are also flexible, which is a benefit to deal with uncertain future developments such as climate change. Using the surface water for floating urbanisation contributes to a number of attributes of future water systems that were summarised in chapter 1. It is a local solution for flood control and a mode of multifunctional use of space. Moreover, it is a flexible and adaptable way of urbanisation.

Floating urbanisation is entering the mainstream construction industry. There is a small yet growing market demand among potential house buyers. Macro level drivers that contribute to the diffusion of this concept include: climate change, sustainability and rapid global urbanisation, and scarcity of land in delta lowland areas. In the Netherlands, mainstreaming of floating urbanisation

is facilitated by a number of meso level developments. While national water management policy demands more water retention capacity in urban areas, a large proportion of surface water is a threat for the successful economic exploitation of urban development projects. Therefore, there is a need to make economic use of the surface water area by multifunctional use of space. Mainstream construction regulations and financing arrangements are increasingly applied to floating projects. Floating urbanisation is more and more included in official policy and regulation. Technical developments, such as high performance floating foundations and floating utility units enable development of large scale water based urbanisation. There is a strong, yet small commercial market that is rapidly developing. Influential stakeholders such as the municipality of Rotterdam, sustainability platform Urgenda and Delft University of Technology have embraced the concept of floating cities.

The national survey results in chapter 10 show that the waterboard and municipality respondents are not convinced of the contribution of floating urbanisation to the objectives of sustainable water management. Yet, almost half of them expect application within their working area within five years. None of the respondents had experience with this concept and the knowledge level was generally low.

Current obstacles to further mainstreaming of this technology lie mainly in the lack of receptivity of stakeholders, which consists of a lack of knowledge, willingness to participate and lack of capacities. This is in particular the case for the unfamiliarity of local government staff with issuing permits for floating urbanisation. The lack of knowledge of applying land based construction legislation on floating developments, is known to be a major obstacle. This lacking receptivity is unsurprising given the fact that floating urbanisation is still a small market and few stakeholders have experience with this innovation.

Risks of floating urbanisation include the loss of open space, the technical quality of floating constructions, and unknown water quality impacts. A potential way to address this problem is capacity building through well-designed, well build, and well maintained demonstration projects that are carefully monitored and evaluated. This will produce experiential knowledge among contractors, local government employees, utilities and residents.

11.4 Mainstreaming of urban water management innovations

Despite the necessity for cities to make better use of local resources and the availability of reliable and affordable technologies, the current water sector is still focused on improving threshold capacity by optimisation of the current system. Unless urban water management innovations are included in the mainstream day-to-day practice of all urban water professionals, these innovations will remain isolated in small scale demonstration projects.

Chapter 7 presented two conditions that are essential for mainstreaming of urban water innovations. These conditions are: including urban water management innovations in spatial development, and stakeholder receptivity to urban water management innovations. These conditions are related. Stakeholder receptivity determines if innovations are included in urban development. However, also other factors are important such as timing and the way the process is organised. In Rotterdam long term envisioning and the presence of a non-official policy process explained why innovations were adopted in official policy. Based on the findings of the case studies, literature, and the national survey, the two key conditions are discussed further.

The national survey demonstrated that urban water management professionals do not seem to be convinced of the necessity of transforming the urban water system. According to them, there is no need for large-scale implementation of urban water management innovations. Most

respondents are convinced that the objectives of sustainable urban water management can be achieved by optimisation of the current water system. Long term threats such as land subsidence and droughts were not mentioned as most urgent problem by any of the respondents. These are problems that cannot be solved with conventional water management. The effects will only be noticed in the long term. Therefore, long term envisioning may increase awareness and association of professionals with these problems. At the same time, it may contribute to a higher proportion of professionals that are convinced the urban water system should be transformed.

Long term envisioning in a collaborative process can lead to the uptake of urban water innovations in spatial development. In this thesis, this was illustrated by the example of Rotterdam Watercity 2035. The literature on transition management and social ecological systems also stress the importance of long term envisioning. It can increase the awareness and sense of urgency of long term problems. Apparently, urban water managers see vision development as something location specific. The respondents in the national survey did not give priority to developing a national overarching vision on urban water management.

According to the interviewees in Rotterdam Watercity 2035, a key success factor was that vision development was a non-official policy process. The non-official status of a contest decreased the political risk. If it failed, it would just be a lost contest. The contest created an occasion for a cross-disciplinary cooperation and the generation of extreme ideas for an unusual long time horizon. In a formal negotiation process working towards an official policy document, these extreme ideas would probably not have been accepted. The strict selection of participants, executive support and the status of the contest created a high prestige and priority for this unofficial process. To a certain extent, the Transition SUW project can also be seen as a non-official envisioning process. The results that were not favourable to decision makers were treated as theoretical research findings. This was clearly the case with local water supply in chapter 4. Useful results for decision makers were eventually applied in actual projects. This was the case for using the watersystem as energy source and floating urbanisation. The creation of space to develop ideas that are not a threat to the official policy is a useful strategy to contribute to innovation in urban water management.

Cooperation between spatial planners and water managers is a key condition for urban water management innovations to be included in the spatial development process. In the Rotterdam Watercity 2035 case, cooperation led to a change in stakeholder perception that facilitated the inclusion of innovations in urban planning policy. The professionals in the national survey were also convinced that cooperation with other sectors is required to achieve the objectives of sustainable urban water management. In particular, strengthening the link between water management and urban renewal was seen as an important element. This finding corresponds to the broader national change in Dutch water management in which spatial planning and water management become more and more integrated. It also links to recent urban water management approaches in which the connection with urban planning and social amenity is highlighted.

The presence of a network of change agents that connects water managers and spatial planners can have a significant influence on official policy. The change agents that created the vision of Rotterdam Watercity 2035 had a strong connection to the mainstream policy makers. At the same time, they were convinced that the urban water management objectives could only be achieved through cooperation and the introduction of innovative solutions. The network of change agents in multiple organisations that emerged during the process, continued to exist after the contest. It formed the foundation for the development of official policy in Waterplan 2. Also the international literature provides numerous examples of the important role of change agents,

policy entrepreneurs or champions. The transformative capacity in urban water management may therefore be increased if urban water institutions better succeed in recruiting and maintaining change agents. In Heerhugowaard, most of the technical staff was working there for years. They had no reason to leave because they had the opportunity to work on exciting projects. The potential of change agents in organisations may be optimally utilised if they are offered an enabling context in which they can function. The change agents in Rotterdam that were interviewed in this research, received considerable freedom from their superiors to work on vision development and innovation, next to their daily tasks.

In Rotterdam, the cooperation process of waterboards and municipality led to a shared understanding of the urban watersystem. Reframing of the problems was an important element in the cooperation between water managers and designers. They learned to understand each others stakes and cooperate from the start. The designers learned that designing with water was ‘fun’. They developed a shared mission to combine the objectives of spatial planning and water management. Water managers learned that urban renewal processes provide a ‘window of opportunity’ to include water retention in the urban landscape. This capacity of waterboards to anticipate on city planning may be strengthened further if they develop the spatial planning expertise of their organisations by strengthening cooperation with urban planners, training their staff in spatial planning, and hiring spatial planning experts. The results of the national survey demonstrated that urban water managers see experience with spatial planning as the second most important priority factor to be improved. The required improvement can be achieved by ensuring more frequent and more intensive cooperation between urban water managers and spatial planners, for instance in long term vision development. This can also contribute to building trust between them, another top five priority factor in the national survey.

Maintaining continuity of knowledge and expertise in the urban development process is required to secure implementation and functioning of urban water management innovations. Innovations should proceed through all the phases of spatial planning, authorisation, location development, feasibility study, design and building preparation, building process and maintenance phase. However chapter 8 and chapter 10 of this thesis showed that there is disconnectedness between the urban water management policy community and the implementation community. Continuity can be secured by making connection between the phases to secure that original intentions are maintained during the feasibility study and design phase. This should be done by transferring explicit knowledge in the form of policy documents and contracts. Tacit knowledge should be transferred by involving people in more phases of the urban development process instead of only one.

This thesis provides examples of policy and planning with multiple stakeholders. However, water systems that combine different urban functions are facing problems with regard to operation and maintenance. The follow up projects of Waterplan 2 show that the question of multi-organisational financing of these facilities can be resolved through a negotiation process at the political level. However, an important question remains who should be responsible for operation and maintenance of multifunctional urban water management infrastructures. A possible solution is the establishment of private public partnerships with a joint responsibility for the design, construction, financing and maintenance of technical urban water management facilities.

Stakeholder receptivity was identified as the second key condition for mainstreaming of innovations. Regime stakeholders need to be open to the concepts that are developed by change agents in envisioning processes. In Rotterdam, water management traditionally received little

priority. Urban planners discovered that water had the potential to make the city more attractive to citizens and companies. This created a willingness to include water innovations in urban planning. Solutions that were developed in the Rotterdam Watercity 2035 process were seen as a potential contribution to the urban challenge. As a result, politicians were willing to support the vision. The waterboards saw the vision as an opportunity to realise their water retention objectives in an urban environment where space for water retention is scarce. As a consequence, many ideas that were developed in Rotterdam Watercity 2035 were eventually included in official water management policy and are now being implemented in practice.

In Heerhugowaard, using the urban water system as energy source was seen as an opportunity for the reduction of CO₂ emission. It was a potential contribution to the municipal objective to achieve a CO₂ neutral emission status by 2027. Moreover, it was a potential solution to obtain economic benefit of the large surface water area. The waterboard was positive because the temperature decrease in summer would decrease the problem of algae bloom and eutrophication. The floating urbanisation case study demonstrated that this technology is a potential solution to high cost of water retention in new urban developments. The case studies in this thesis demonstrate that innovations that contributed directly to the objectives of spatial development were eventually included in the spatial development process. The contribution to the objectives of urban development created support and commitment of elected officials. In the national survey this support and commitment was one of the key priority factors for change in urban water management. Linking water management with other, more urgent, societal issues may therefore put water higher on the political agenda and create a sense of urgency that is often lacking in water management. This can provide an enabling context for the adoption of urban water innovations.

Involving key stakeholders in urban water infrastructure planning is a pre-requisite for mainstreaming of urban water management innovations in day-to-day practice. House owners need to be involved in urban water innovation because they are large property owners and major investors. In Rotterdam, for instance, more than 70% of the houses in Rotterdam are owned by social housing corporations. Water storage will have to be located on their properties if the water retention objectives are to be realised. Currently, there are no strong incentives for house owners to cooperate. A potential incentive could be that water retention can contribute to upgrading neighbourhoods and increasing the value of real estate, in particular in the old and deprived neighbourhoods. This may be a motivation for housing cooperation to participate in water retention projects. For this purpose, the interdisciplinary cooperation between water managers and spatial planners needs to be translated from the strategic level to the project level where housing corporations are implementing urban renewal projects. This can be done by involving them from the initial phases in urban water infrastructure development. Urban water managers are convinced that involvement of citizens in urban water projects is key priority factor to achieve the objectives in urban water management. Private house owners will possibly have an incentive to cooperate in implementing local urban water solution, if sewer and waterboard taxes are made dependent on the burden of the private property on large scale networks. In that case, water retention in a private garden leads to a lower water tax. This could stimulate local water retention and local water use for residential purposes. At the same time, it could create a market for local water management technologies. Also in reducing urban flooding vulnerability involving citizens can have benefits. The example from Japan in chapter 3 demonstrated how better communication of flood risks to citizens can contribute to an improved coping capacity.

Involvement of the private sector is also important. The private sector, for instance the building industry, was not involved in the process of Rotterdam Water City 2035 and Waterplan 2. They are now involved in a couple of follow up projects. Private contractors and developers are crucial stakeholders to involve. It is through their activities that urban development and urban redevelopment projects become reality. The floating urbanisation case study demonstrated that the presence of a strong niche market can be an enabling factor for mainstreaming of technologies. The availability of a viable business case is important. International literature demonstrates that it is a key enabling factor for changing the urban water management sector. It was also an enabling condition for the application of the urban water system as a source of local energy in chapter 5. However, urban water managers do not seem to be convinced of the necessity of a viable business case. In the national survey, this factor received the second lowest priority. In the Netherlands, urban water management is still public sector driven. With more involvement from the market in innovative water retention infrastructure, there will be more suppliers, more investments and therefore, more research and development. This will lead to better and more competitive local urban water management technologies.

Incentives for building contractors to construct urban water management innovations are currently lacking because they are responsible for the damage in building projects. Moreover, their clients, citizens and housing corporations, rarely ask for innovative water retention on their property. If these facilities are installed, they are not acknowledged by the waterboards. Operation and maintenance on private property are impossible for waterboards. The functioning of the system cannot be guaranteed. Consequently, the statutory obligations and responsibility of the waterboard cannot be met. Incentives for the private sector to participate in urban water innovations may include awards, stricter regulation and increased competition. In Japan a larger market for water recycling was created by the legal obligation to include water recycling in all building projects larger than 10,000 m². However, the professionals in the national survey were not at all convinced of the importance of binding targets and standards to achieve the objectives in urban water management. Binding targets received the lowest priority of all 20 factors that were studied in the survey. In the national survey, the availability of subsidies was considered the least important reason to choose an innovation. The reliability of a novel technology was the most important consideration. Rather than giving subsidies, governments can play a role in reducing the risk for the private sector to implement innovations by guaranteeing the replacement of alternative technologies that are not yet completely trusted by developers.

The capacity of urban water organisations to perform different roles than the traditional roles, is an enabling factor for mainstreaming of urban water management innovations. Using the urban water system for new functions implies that urban water managers will have to fulfil new tasks that are unfamiliar to them. An example of a new role is the waterboard as a developer of water plots for floating urbanisation. The Heerhugowaard example showed that the municipality is considering starting a municipal energy company to utilise local energy supply. The water utility company may become a facilitator of local water supply. A possibility is that local water treatments are owned by residents and that the water utility develops a new business model based on supplying technology and service contracts. However, stakeholders are not likely to perform these roles unless the full receptivity continuum is fulfilled. This means they have to be aware of the options, convinced of the benefits to their organisations, possess the skills and knowledge to execute these roles, and have sufficient external incentives to do so. Executing other roles than the traditional responsibilities can be facilitated by creating statutory space in the mission of organisations to perform other tasks. This could stimulate innovation. An important remark to

make here is that such space is contrary to the current trend of efficiency, benchmarking, and focusing on the 'core business'.

New roles also imply that organisations have to become familiar to new tasks. New roles require new expertise, new knowledge and new experience. This requires a learning process that can be facilitated by workshops, guidelines and training programs. Also demonstration projects with innovative technologies potentially assist in developing these capacities. By starting small scale, the risks are kept at a relatively low level for organisations that are starting to execute new roles. At the same time, these projects also contribute to the demonstration, and further development of the reliability of innovative technologies. Reliability will further contribute to mainstreaming of these technologies. In the national survey, reliability appeared to be the most important consideration to choose an innovation. Demonstration projects should not only demonstrate that technologies work. Other objectives are learning and further improving the technology. In the national survey, it appeared that although respondents are convinced that the innovations will be applied in the near future, they also thought the potential contribution of these technologies to change the overall water system was low. Apparently, the respondents expect demonstration projects to be executed, but also expect them to remain isolated. This means that replication and improvement are important conditions for demonstration project to be eventually successful. Replication and improvement should lead to a continuous learning process. Given the low perceived contribution of urban water management innovations to contribute to the objectives of urban water management, there is also a need to better demonstrate the potential of new technologies to change the performance of the overall urban water management system.

Improving the available knowledge about the local urban water system was regarded top priority by the professionals. The reliability of innovations was the most important consideration to apply them. Knowledge of the local water system can be improved by better monitoring and evaluation. Connecting water management to research projects may also contribute to improved system knowledge. The Transitions SUW was an example as a collaborative project between researchers and practitioners. However, this project only lasted four years. Longer cooperation will be necessary to have a long term effect. Demonstration projects should be combined with capacity building programs, evaluation and monitoring to allow for improvement and replication of these technologies on a wider scale. Without this condition, the application of innovative technologies will remain limited to showcases and iconic demonstration projects, with no significant impact on the overall performance of urban water systems.

Building experience and developing knowledge is necessary to advance innovations in urban water management. The respondents in the national survey generally had a low knowledge level of the surveyed technologies, with the exception of local water retention. Moreover, they were not yet convinced that innovations are essential to achieve sustainable water management. The respondents who had recent professional experience with innovative technologies had a more positive attitude towards the expected implementation timeframe of two technologies. They also had more knowledge of innovations in general. Possible measures to enhance the receptivity of professionals should therefore include increasing the exposure of professionals to innovative practice to strengthen tacit knowledge. However, this will only be attractive to career driven professionals if experiential knowledge is appreciated and included in reward mechanisms of organisations.

11.5 Reflection and general recommendations

Based on this thesis the following recommendations are made to decrease vulnerability of cities and improve mainstreaming of urban water management innovations.

The first recommendation is that cities start to build experience with using local water resources and local flood control solution in addition to external infrastructure. They should move towards a portfolio of resources to decrease the dependency on large scale infrastructure and external resources. The vulnerability of urban areas is increasing due to uncertain future developments such as climate change, urbanisation and land subsidence. This thesis has demonstrated the potential of the local urban surface water system to provide local resources to reduce vulnerability. A key requirement for building experience with local solutions is to include evaluation and replication in the design of demonstration projects. Evaluation and replication increases the competitiveness of innovations against centralised mainstream infrastructure. It results in a continuous learning process for the involved stakeholders. To develop experience and knowledge to fulfil new roles, demonstration projects should be established in combination with research and development programs. The role of technical experts should change from a deciding role that is based on internal recognition, to an essential supplier of reliable knowledge to public decision making processes concerning the future water supply of cities. The recognition of scientists should be more based on the provision of useful knowledge to solve urgent societal problems, next to the internal appreciation of publishing in peer-reviewed journals. Given the fact that science is almost entirely supported by public funding, researchers should at least feel partially responsible for making a connection between research findings and practice.

The second recommendation is to increase the adaptability of urban water infrastructure. Currently, the time horizon of urban water management planning is defined by a five-year planning cycle. However, the urban water infrastructure lifespan is 30-70 years. It is therefore unsurprising that mainly optimizing interventions are applied. Cities have to deal with many uncertainties including the effects of climate change, urbanisation and resource scarcity. The high technical lifespan leads to a technical and institutional lock in that excludes promising options that are not compatible with the centralised system. To prevent irreversibility and increase flexibility, it is recommended to decrease the lifespan for which urban water infrastructure are designed. This can be accomplished through spatial reservations in urban planning that allow for future adaptations and through the application of more local solutions. Local solutions can be adapted more easily because they are not part of a large network. Many local technologies require active participation of citizens as a source of context specific knowledge. These technologies should be adapted to local circumstances. Investments to engage citizens and develop the knowledge and skills of community to fulfil these roles are essential to make this step. This will also contribute to the development of a private sector driven market for urban water management innovations.

The third recommendation is that urban water management policy makers include long term envisioning with multiple stakeholders as a standard component of urban water management policy to increase awareness of long term problems and possible responses. This may increase receptivity to innovative options and increase the sense of urgency for developments that will cause major problems in the long term but are not urgent in the short term (e.g. land subsidence). Long term envisioning may also contribute to mobilisation of resources of multiple stakeholders and may lead to a joint ambition. In addition, it may give change agents the opportunity to realise innovations. In two case studies in this project, Rotterdam and Heerhugowaard, long term

envisioning and the high ambition of the municipality provided a window of opportunity for innovative technologies and change agents.

The fourth recommendation is that policy makers adjust change policy according to the full receptivity continuum of the stakeholders that are expected to implement these changes. The advice is not to make better policy documents, but to work on better implementation of policy by taking into account the receptivity of the organisations that will have to implement it. Professionals in urban water management in the Netherlands are not convinced that urban water systems should be structurally transformed. Despite urgent problems on the long term such as land subsidence, energy scarcity, the affordability of urban water infrastructure and depletion of nutrients, the sector is convinced these issues will be resolved by optimisation of the current system. Possible measures to enhance the receptivity of professionals to innovations should include increasing the exposure of professionals to innovative practice to build experience. However, this will only be attractive to career driven professionals if experiential knowledge is appreciated and included in reward mechanisms of organisations. More attention should be paid to associating change programs with stakeholders' interests and addressing the capacity of stakeholders to design, implement and maintain alternative water systems. Capacity building programs to improve stakeholder capacity are required. These programs should include the facilitating of change agents, improving the capacity within organisation as well as the capacity to cooperate between organisations to successfully contribute to change urban water management.

The fifth recommendation is the creation of supportive institutional frameworks and legal incentives. This includes creating of legal space for organisations to execute tasks that indirectly contribute to the mission of the organisation yet do not directly fit within their responsibility. Urban water organisations should no longer be rewarded based on effective execution of their fragmented statutory tasks, short term targets and costs minimisation. Instead, urban water organisations should be judged on their contribution to the total system performance and long term targets. This creates room for stakeholders to be involved in long term collaborative projects. Institutional mechanisms should be developed and installed to support realisation, operation and maintenance of multifunctional water systems with multiple stakeholders. These mechanisms should facilitate the uptake of new roles by stakeholders, for instance the extraction of heat by the waterboards to supply sustainable energy and improve water quality. A possible example is the establishment of private-public partnerships that are responsible for the entire lifecycle of a local technical urban water management facility. This would enable the tendering of complete development trajectories, and incorporation of construction and maintenance knowledge in the design phase. To secure public interests, selection of partnerships should be based on costs, quality and system impacts rather than costs only. This should be supported by a management culture that is leadership driven rather than responsibility driven. This means urban water organisation will have to do what is considered beneficial instead of doing what is legally prescribed. These changes will increase the potential of mainstreaming urban water management innovations to everyday professional practice in public private partnerships.

The last recommendation is to create a commercial market for urban water management innovations. At this moment, there are hardly any incentives for developers and citizens to demand urban water management innovations. Such incentives could be created by awards, subsidies, increased competition among developers, and binding targets and regulations with regard to water management for instance on water robust buildings, source control, water quality, quality of the urban landscape, and integration with water management. For citizens, waterboard taxes should be made dependent on the surface of connected paved area to the sewer system to

stimulate local water retention and water use on private property. Table 11.1 summarises changes that need to be made to move from mainstream urban water management toward transformative urban water management.

Table 11.1 Elements of mainstream water management compared to transformative water management

	Mainstream	Transformative
Urban water resources	One external source	Portfolio of water sources, centralised and decentralised
Urban flood control	External protection, discharge capacity	External protection, local retention and flood proof urban environment
Innovative demonstration projects	Showcase Technology demonstration	Build experience with new options, evaluate, improve, replicate. Evaluate potential for complete system
Role of expert	Decisive Incremental improvement of system fragments	Source of reliable science Total system engineering Developing multiple options
Role of water scientists	Recognition based on acceptance of publications by specialised technical community	Recognition based on provision of useful knowledge to solve urgent societal problems
Planning timeframe	5 years horizon	30-70 years horizon
Infrastructure lifespan	30-70 years	<20 years
Infrastructure typology	Centralised, generic solution, low flexibility	Context specific, flexible, reversible
Infrastructure Innovations	Incremental	Incremental and transformative
Role of citizens	Passive consumer	Source of context specific knowledge, co-producer
Planning Culture	Deadline driven	Flexible
Policy	Same policy regardless of stakeholder receptivity	Policy adjusted according to level of receptivity
Main instruments	Awareness campaigns, legal incentives	Involve stakeholders in decision making Capacity building
Most urgent problems	Short term	Short term and long term
Type of vision development	Monofunctional, internal	Multifunctional, multiple stakeholders
Accountability Frameworks	Effective execution of fragmented statutory tasks, costs minimisation	Co-responsibility of multiple organisations
Implementation Tendering procedures	Prescribed solutions in separate pieces, tendering procedures based on lowest costs	Tendering of complete development trajectories, Selection based on costs, quality and system impacts.
Reward mechanisms	Fulfil procedures, within budget, within projected timeframes	Contribution to total system performance
Management style	Authority driven Responsibility driven Measurable short term targets	Leadership driven System performance driven Long term performance
Incentives for developers and citizens to apply local urban water innovations	None	Awards, subsidies, increased competition among developers, binding targets and regulations

11.6 Integrative research approach and impact on practice

One of the key requirements in the project was collaboration with practitioners, bridging the social science/ technical science gap and to make an impact on practice. In two of the three cases, research results from this project were included in official decision making processes and spatial development processes. This was the case for the use of the urban water system as an energy source, and floating urbanisation.

Using the urban water system as an energy source is now in the process to be applied to 2816 houses, which will make it the largest ATEs+ development in Europe. The Environmental Impact Assessment was successfully executed and the permits have been requested. Floating urbanisation was taken up by the municipality of Rotterdam. The municipal board decided positively about the project. On 28 October 2008, they commissioned the municipal department to start working to develop a business case and project specification. The project should be finished in May 2010. Also the other project partner cities, Heerhugowaard and Amsterdam have shown interest in this concept.

The use of local water resources has not been taken up in official follow up projects. Although this is the concept that is most common abroad, it was the only concept in the Transitions SUW project that did not make an impact on practice, even though rainwater harvesting was considered an attractive option.

Overall the integrative research approach can be considered a useful way of working. Scientific results were produced and distributed, at the same time relevant findings for practical case studies were developed. Two types of products were produced: project reports that were predominantly in Dutch and scientific articles that were predominantly written in English.

Research was not a short term priority for most project partners, except the researchers. The challenge was to connect the research questions to knowledge needs in the case study cities. The flexibility in the project planning to change the schedule and executed case studies at a time when the partner cities needed them was an important factor. Each year, there were two plenary meetings with the project partners. During these meetings, decisions were made which case studies would be done.

The broad knowledge base in the consortium that included water technology, water management, energy supply and transition management proved to be valuable for the transdisciplinary research approach.

11.7 Recommendations for future work

A number of recommendations for future work can be made based on this thesis. More research on climate change impacts on local urban water systems is needed to quantify climate impacts on urban water systems more precisely. Subsequently, it is needed to more specifically assess and quantify the vulnerability reduction by local urban water management concepts. More research is needed to operationalise the added value of coping, recovery and adaptive capacity compared to threshold capacity strategies. In addition, knowledge is needed on how to design flexible and reversible infrastructures to improve the adaptive capacity.

Technical research could focus on investigating the potential of the innovations that were described in this thesis. Because they are relatively new technical concepts, there are many opportunities for improvement. For the use of local water resources, it is recommended to do research on the feasibility of mixed systems that use local water resources for low quality residential purposes and external water resources for high quality purposes. This might be an optimal mix of water sources to reduce vulnerability, although more research is needed to more

specifically estimate the vulnerability reduction of such mixed systems. In addition, field research and practical experiments on the risks of local water supply is needed. The design of urban water systems could be changed to maximise the potential amount of energy that can be harvested. It is recommend to do research to develop design guidelines to make urban water systems more suitable to function as an energy source. In addition, detailed research on the water quality improvement due to this concept is needed. For floating urbanisation, research should concentrate on developing accessibility structures that include technologies for local water and energy supply. Water quality impacts should be studied. Moreover, the applicability of floating structure technology for building cities on weak soils should be investigated.

Social research in urban water management is recommended to focus on developing institutional mechanisms to implement, maintain and operate multifunctional water systems with multiple stakeholders. More research is needed on the role of experts and citizens in transition processes. In addition, strategies should be developed to close the gap between the policy and strategy community and the construction and implementation community. A national survey to investigate receptivity of the private sector for urban water management innovations would be useful. The national survey found a small, distinct group of 'transition thinkers' among the water management. This was a small group with a strong internal consensus about a number of issues. The advice is to do research to learn more about the perception of this group because they may function as catalysts for change in urban water management.

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Appendix

The Transitions SUW Project

This thesis is based on results from the research project 'Transitions to more sustainable concepts of urban water management (Transitions SUW). This project (2005-2009) was executed by a consortium of 12 organisations as part of the research program Leven met Water (Living with Water). This program is: 'a Dutch knowledge impulse program in which (international) project consortia collaborate to achieve changes in water management. Living with Water stimulates collaboration between the domains of water management and spatial planning, science and practice, economy and sociology, both at home and abroad. Practical experiments bring these different disciplines together, amassing new knowledge and experience. The program functions as a catalyst for innovations.'¹¹

Consortium

The organisations in the Transitions SUW project cover a wide range of stakeholders in urban water management. Research institutes, engineering firms, local authorities and waterboards cooperate in this project:

- Stichting Leven met Water
- STOWA
- Gemeentewerken Rotterdam
- KWR Watercycle Institute
- Tauw BV
- Deltares
- Ecofys
- Gemeente Heerhugowaard
- Waternet Amsterdam
- Hoogheemraadschap Hollands Noorderkwartier
- Technical University Delft
- Erasmus University Rotterdam

¹¹ www.levenmetwater.nl

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Bert Palsma and Corné Nijburg improved the quality of the Transitions project by remaining critical and by continuously reminding me that the purpose of the project was not to develop more technical innovations but to develop insights on implementation in practice. Early in the project, Paul Baan gave me the advice to focus on vulnerability rather than sustainability. His advice definitely contributed to my research. Lucas van de Winckel and Gijs van Wijk participated in the Heerhugowaard water for sustainable energy case study. Rutger van der Brugge contributed to this work by cooperating with me in the Rotterdam case study. He is a great person to work with. Many thanks also go to Cees Kruithof and John Jacobs. Their participation in the project not only allowed me do innovative case studies, they are also continuously demonstrating that there are visionary, realistic thinkers in some Dutch municipalities. I would like to thank Govert Geldof for his advice to start with case studies early in the project (parallel approach), rather than doing them at the end (serial approach) as was originally planned. This has made the project much more interesting. I would like to thank Gerard van den Berg for cooperating with me in the Heerhugowaard local water resources case study. In addition, I am grateful to the other participants of the Transitions project Peter Hesen, Eilard Jacobs, Annette Beems-Kuin, Derk Loorbach, Joost Lankester, Wim van der Vliet, Ezra Swolfs, Wytse Dassen, and Bert van Ee. I am grateful to Sylvia Jansen and Roland Goetgeluk for their valuable knowledge on questionnaire based research and methodology. Also, I would like to thank Joost Icke and Ruben Dahm for their cooperation in the last phase of the project. Ruben also worked together with me in writing publications on receptivity. His sharp thinking helped to improve the drafts of several publications. Thanks also go to Wenneke Lindemans for designing the cover of this thesis. I would like to thank Dries Hegger for our good discussions on the social aspects of urban water management.

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founding father of water sensitive urban design. I also have good memories of the work on the book *Urban Water in Japan*. I am grateful to Kenichi Koga for his hospitality and great knowledge of Japanese water management. My traineeship at Saga University in 2005 was the starting point for my study on Japanese water management. Many thanks also to Shoichi Fujita for being our guide in Tokyo on an unforgettable technical tour. I would like to thank Fransje Hooimeijer for being an excellent editor and working companion. Many thanks also to the other authors of the *Japan Urban Water* book. Jun Matsushita contributed to the quality of the innovation chapter of the *Urban water in Japan* book by remaining critical.

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Rutger de Graaf
Delft, september 2009

Curriculum Vitae

Rutger de Graaf was born in The Hague, the Netherlands, on 12 February 1980. He finished his secondary education in 1998 at the Alfrink College in Zoetermeer. From 1998 to 2005 he studied Civil Engineering at Delft University of Technology. During these years, he participated in various extracurricular activities. He was president of a student association and organised a symposium and a study tour on sustainable urban development in Brazil. He completed his M.Sc. cum laude in April 2005 with the thesis: 'Transitions to more sustainable urban water management and water supply'. After his research on flood control in the Jobaru river basin at Saga University in Japan, he started to work as Ph.D. student at Delft University of Technology in October 2005, again on the transition to more sustainable urban water management. His Ph.D. research was part of the 'Leven met Water' program. During his research, Rutger co-organised the Young Scientists Workshop on Urban Water Innovation and two international symposia. He collaborated with urban water management researchers from several countries, including Japan and Australia. He was invited speaker at one international conference, and two international workshops of the IWA/IAHR working group on Water Sensitive Urban Design. In 2008, Rutger was included in the 'Dutch Masters, Pioneers in International Business' of the Agency of International Business and Cooperation (EVD) of the Dutch Ministry of Economic Affairs. Rutger is founding partner of DeltaSync, a multidisciplinary research and design company that works on sustainable flood proof urban development. With DeltaSync, he was awarded first prize in the international Deltacompetition in October 2006 and first prize in the Dutch Climate Contest in December 2007. Currently, Rutger is involved in sustainable floating construction projects in the municipalities of Rotterdam and Delft, the Netherlands.

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