Intertwining uncertainty analysis and decision-making about drinking water infrastructure

Machtelt Meijer

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Preface

In December 1998 I started my PhD research, which led to this thesis. The research was made possible thanks to the Delft Interfaculty Research Center (DIOC) on the Design and Management of Infrastructures.
Almost nine years, three children and two jobs later I have closed this chapter in my life. The work on my thesis gave me the opportunity to explore the world of uncertainty more in depth. Also it gave me the opportunity to explore some parts of the real world while presenting or discussing my work abroad. I enjoyed teaching the students of System Engineering, Policy Analysis and Management. Of course I preferred some courses I had to teach over others, but overall I considered this to be very pleasant. I feel that the things that I have learned being a PhD student have been useful to me and are still applicable in my current occupation as a policy advisor.
Being a person that likes to discuss my work into some detail, the most difficult part of being a PhD student I found the relative loneliness in the work. In the starting phase of the research I had the benefit of the discussions with fellow DIOC researchers. After about a year these discussions came to an end when everybody entered the stage where their own research had to focus and joint efforts became more of a burden than a help. Luckily there were quite a few PhD students in the policy analysis section that made life at the university fun anyhow.

During my research I came to read a story about a few blind men who describe an elephant by the parts of this animal which they felt. They all described the elephant differently, since one felt the trunk, another one felt the tail, yet another one a fang, etcetera. All these descriptions of the elephant were correct, but all represented just one aspect of reality. Like the description of the blind men of the elephant this thesis represents just that part of reality that I have studied. There are always more aspects of reality that can be studied and sometimes I found it hard to make choices about where to draw the line between what to study and what not to study. But now, with hindsight, I cannot say that I would have made different choices if I had to do it all over again. Changes in the research setup would have been in the details and most certainly in the timing of the different activities. The general idea would not have been changed.

Having said that, I need to thank a couple of people without whom this thesis would not have been the same. To avoid the risk that I leave out some people I will only mention those people that have been most important.
Wil and Tineke thanks for your advise and positive criticism. You both pushed to get the best out of me. Members of the policy analysis section, and especially Leon, Linda and Sonja thanks for making work more than just work. I enjoyed our discussions, lunches and talks about all kinds of things.
I would like to thank my family for their support and their belief in me. My mother and mother in law both took care of the children when the research asked for it. My dad read the thesis to check whether my English was not too bad.
Finally, I would like to thank the most important persons in my life: Gijs, Sam, Lana and Jesse. Life would not have been the same without you. Without your support and understanding this thesis would not have been possible.

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Infrastructures, generally designed to have a long service life, are particularly vulnerable to long term changes that can influence their functioning. Therefore it is important that uncertainties are taken into account as much as possible from the beginning of the planning process of infrastructures.
This thesis focuses on drinking water infrastructure. This type of infrastructure is characterized by a long life expectancy. Changes in the supply of materials (for instance source water, energy, space for building underground networks), technology, and demand for the end product can be expected, but are difficult to predict. These changes can lead to high cost for society when they lead to system failure or obsoleteness of the existing infrastructure.

The main objective of the research was to answer the following question:

> *Can the identification and handling of uncertainties in the Dutch drinking water infrastructure planning process be improved? And if so, how?*

To answer this question, first a literature study was performed, which was used as a basis to develop both a descriptive and a normative framework for the analysis of case studies. These frameworks then were used to analyze four case studies ex post. Finally, a workshop was used to discuss the overall results with representatives from the drinking water field.

The descriptive framework is based on an approach in which a system is described as well as the influences on that system. These influences can come from external variables that cannot be influenced by a decision-maker and from tactics that a decision-maker can use. The effect of both on the system can be observed in changes in the outcomes of interest that a decision-maker has.

The normative framework was developed to evaluate the success of drinking water companies in their efforts to deal with uncertainty. It is based on a causal chain of actions in a planning process that should lead to successfully dealing with uncertainty. It was found to be impossible to measure the success of dealing with uncertainty directly, this would have taken many more case studies and very long time spans that needed to be evaluated. Therefore it was chosen to use indicators of success within the causal chain as proxies for the overall success of a drinking water company in dealing with uncertainty. For each step in the causal chain a indicator of successfully performing this step was identified. The idea was that if each step is performed well, overall success in dealing with uncertainty will follow. The indicators of successfully dealing with uncertainty were:

- The relevance and consistency of the system boundaries and relationships considered
- The richness of inputs and outputs considered
- The explicitness of assumptions made
- The presence of signposts (which are events or thresholds that indicate the changing vulnerability of an assumption) and a contingency plan and the consciousness of the relationship of signposts with assumptions
- The richness, completeness of exploration and the presence of options.

Four cases were studied in retrospect, of which three were recent and one was further in the past:
The four cases that were studied are:

1. The Project Infiltratie Maaskant (PIM) 1972-2000, of Waterleidingbedrijf Oost-Brabant (WOB). This project was set up by the drinking water company to plan for infrastructure that would enable the harvesting and purification of river Maas and Waal water as a source for drinking water instead of groundwater which is the traditional source for drinking water in their region.
2. The Oever-Diepinfiltratie project (OEDI) 1972-2000, of Waterleidingbedrijf Midden Nederland (WMN). This project was meant to enable the winning and purification of water from the Amsterdam-Rijn channel instead of groundwater which is the traditional source for drinking water in their region.
3. The planning of purification facility Jan Lagrand 1973-1999, of PWN, the drinking water company of the main part of Noord-Holland. This project was carried out to realize a large-scale membrane purification facility to expand purification capacity and to be able to deliver drinking water with a lower calcium content.
4) The Lek-duin and the Maas-duin projects 1874-1996, of DZH (Duinwaterbedrijf Zuid-Holland). These projects were carried out to transport water from the rivers Lek and Maas to the dunes near the Hague, were it is purified in a natural way through dune infiltration. Decision-making and planning of these projects were studied for the years 1939 to 1965.

The most important conclusion of the cases was that drinking water companies are very aware of uncertainties and a lot of action is taken to handle them. However, some suggestions can be made to improve the analysis and handling of uncertainties. Firstly, the case studies showed that not all potential critical external influences received the same amount of attention. Political, social en technological considerations were found the most crucial in the cases that were studied. Political and social influences were also found to be most difficult to handle. Secondly, some external influences were recognized in the cases, but were not included in the analysis, because not enough was known about them. For instance in the case of the success of drinking water saving actions this external variable showed to be critical. If this influence would have been considered in more detail maybe other decisions would have been made.
Thirdly, the cases showed that assumptions were made more explicit after they had failed. If they had been made more explicit beforehand maybe decisions to change policy could have been made sooner.
What the future brings is not certain. Drinking water companies therefore include considerations about future options in their decision-making process. Signposts, however, do not play a significant role in decision-making. Because of technological possibilities that now have become available with membrane technology the focus on robustness of tactics has shifted towards the flexibility of tactics. Still it proves to be difficult to justify investments in flexible or robust elements in a design, since no benefits can be showed that reflect a present value.

The research resulted in eleven guiding principles, of which the most crucial seven are discussed here. These guiding principles are based on literature, but also on practical evidence that these principles are important and are felt to be important by drinking water experts:

1. *Study all five categories of external influences (social, economical, political, technological, environmental) in order to uncover the potentially critical ones.*
2. *Use both qualitative and quantitative data*. Also qualitative data can be used to base decisions on. For instance in a devil's advocate approach. Otherwise important notions may be overlooked in decision-making.

3. *Define your system boundaries broad enough and do it explicitly.* This is to make sure that all possible solutions can be considered and are not overlooked. In the OEDI case it was finally chosen to buy water from a neighboring drinking water company. If the system boundaries would have been chosen to search for tactics within the own region only, this tactic might have been overlooked.
4. *Make critical assumptions explicit.* It is important to know which assumptions are made and would have had changed the decision if it would have been assumed differently.
5. *When making estimations don't forget to consider the possibility of the breaking of trends.* Even when trends have not failed yet, always consider the breaking of trends. The change in water demand from ever rising to a stagnation and even a lowering of the demand showed that nothing in this respect is certain.
6. *Monitor developments that can lead to the failing of critical assumptions, preferably in combination with the determination of signposts.* In the case studies it was found that drinking water demand was monitored closely. The monitoring of other crucial external influences got much less attention. In a combination with a signpost, monitoring can be a great help in knowing when decisions need to be reconsidered.
7. *When choosing between tactics, remember that options can also reflect a value. Potential future benefits should be considered in a decision-making process.* It is very tempting to value tactics performance under present conditions. Possible future cost and benefits, however, should be considered as well.

The implementation of good practices will be easier in some companies than in others. It is dependent on the present way of working, the possible benefits that management expects from a different way of working and the extent to which investment is possible. The suggested approach works only if there are alternatives to choose from and if there is a belief that uncertainties do matter.

Chapter 1 Introduction

If you don't know where you are going, any road will take you there.
Lewis Caroll, Alice in Wonderland

1.1 Uncertainty and the planning of infrastructure

The world in which we live is subject to changes that are not always predictable. The timing and impact of these changes are uncertain and cannot be known. There are a number of reasons why it is important to characterize and deal with this uncertainty explicitly. A good general reason for doing uncertainty analysis is given by Morgan and Henrion (1990): "Many real world decisions are not made by a single person at a discrete time. More typically, a decision process may involve multiple actors making explicit and implicit decisions over an extended period. A piece of analysis will be more useful if it treats the uncertainty explicitly allowing users to evaluate its conclusions and limitations better in the changing context of the ongoing decision process." This is especially true for infrastructures, which are characterized by a long service life and of which the proper functioning over an extended period is critical to society; think of the relevance of sewers to public health or the relevance of road infrastructure to mobility. These characteristics make it very important that infrastructure design and planning is based on a good sense for the possible consequences of future events.
Infrastructures, generally designed to have a long service life, are particularly vulnerable to long term changes that can influence their functioning. Therefore it is important that uncertainties are taken into account as much as possible from the beginning of the design process of infrastructures. Infrastructure may turn obsolete when uncertainty about future circumstances is not dealt with properly in design and planning processes (Lemer, 1996). Omission of uncertainty analysis results in untimely recognition of events that may lead to stagnation, delay, or early termination of a project, to construction of infrastructures which are not acceptable to the public or that do not meet foreseeable future requirements, or to the regret that better solutions were not found (Hall, 1980). Negative effects of unexpected changes can never be prevented completely, but nevertheless to a certain extent.

This thesis focuses on drinking water infrastructure. This type of infrastructure is characterized by a long life expectancy. Changes in the supply of materials (for instance source water, energy, space for building underground networks), technology, and demand for the end product are to be expected, but difficult to predict. These changes can lead to high cost for society when they lead to system failure or obsoleteness of the existing infrastructure. Therefore dealing with uncertainty as best as one can is very important. The planning and design of water works should guarantee that sufficient healthy drinking water can be supplied in the future at acceptable cost.
The drinking water infrastructure is organized relatively simple and the context in which it is operated is relatively stable. For this reason it was chosen to study this sector. This made it easier to derive basic notions that later could be generalized to more complex situations.

A good example of unexpected circumstances and their consequences for drinking water companies can be found in the consequences of the oil crisis in the 1970’s for the industrial drinking water demand. For example drinking water company Europoort (now called Evides due to a merger with water company Delta), which has many industrial customers, faced a major drop in demand, and was left with a large overcapacity in their water purification facility. Another, more recent, example can be found in the consequences of the stabilization of domestic drinking water demand. Many drinking water companies planned for a lasting growth in demand, which however did not occur. The stabilization of drinking water demand

made some of them reconsider their plans. In the case of WOB (Waterleidingbedrijf Oost-Brabant) this happened when construction of facilities already had been started. Water system planners in both previous examples had anticipated growth of water demand and were not prepared for a decline in water consumption.
Losses as a result of unforeseen developments are not restricted to drinking water infrastructure. There are other examples of infrastructures that failed to meet a change in demand for the goods or services it supplies, e.g. the port of Amsterdam that was expanded with a container terminal that has been unused for many years and the nuclear power plant at Kalkar, Germany, that was never put into use for unforeseen political reasons. Ex-post analysis of these examples indicates that critical decisions made during the planning process were based on the assumption that the possible future circumstances were understood and could be anticipated. Not all future events however can be foreseen in the planning of water supply systems or any other infrastructure. But we hypothesize that, if a wider range of possible futures would be considered in a structural manner, losses would be less.
System analysis provides methods that can be used to deal with uncertainties in the planning and design processes of drinking water infrastructure. This thesis addresses the question whether and how system analysis methods can be used to improve the current Dutch planning process for drinking water infrastructure.

In the Dutch drinking water sector dealing with uncertainties has become an important item. This can be concluded from initiatives like 'De Kartonnen Doos' in which multiple scenarios for the future Dutch drinking water world were described (see for instance H_2O (2002) No. 21, and H_2O (2003) No. 7).

1.2 Research questions

The main objective of the research was to answer the following question:

Can the identification and handling of uncertainty in the Dutch drinking water infrastructure planning process be improved? And if so, how?

To be able to answer this question the following sub-questions must be answered:

Key questions:

1. What is a good definition of a successful uncertainty analysis and handling in a planning process?
2. What methods and techniques are theoretically suitable to analyze and handle uncertainty in respect to planning decisions (specifically in the case of drinking water infrastructure)?
3. How is uncertainty analyzed and handled in the current (and past) practice of the drinking water infrastructure planning process?
4. What is the difference between normative theoretical notions on uncertainty analysis and handling and the described practical reality?
5. What parts of the current practice of uncertainty analysis and handling can be improved?

Background questions:

6. What is uncertainty? Uncertainty needs to be defined as it is used in this thesis. There are different classifications of uncertainty. It is necessary to indicate what these classifications are and which classification is used in this thesis to address uncertainty in planning.

7. What is uncertainty analysis and handling? As there are many classifications for defining uncertainty, as many ways there are to analyze it and dealing with it, depending on the reason of analysis and the background of the analyst or decision-maker. It needs to be indicated how uncertainty is perceived in this thesis and how this perception relates to different possible ways of analysis and handling uncertainty.
8. What does the planning process look like from a theoretical perspective? Some background on how planning takes place is necessary to determine where in the planning process dealing with long term uncertainty is crucial.
9. What are specific characteristics of the planning process of Dutch drinking water infrastructure? To be able to relate the results of this thesis to other infrastructure than drinking water infrastructure, or to drinking water infrastructures in other countries an analysis of similarities and differences is needed.

1.3 Research design

The research is based on two basic activities, namely literature study which was used to develop a research framework and empirical research. The literature study formed the basis for a descriptive and normative framework. These frameworks were then used to describe and study four cases. The case study research resulted in a description of the events that took place in the course of time with respect to the cases and an analysis of the role that uncertainty played in the decisions over the periods investigated. Based on the case study evidence conclusions were drawn on how uncertainty is dealt with in the drinking water practice. These conclusions were then evaluated in a workshop with drinking water experts.

The research set-up also could have been done differently: first studying cases and then developing a theory about what can be learned from the empirical results. The reason why this was not done is that many theoretical notions were available, but were never applied to in the drinking water infrastructure practice. The research set-up, as it was chosen, made it possible not only to synthesize existing theoretical notions, but also to use the case study results to add to them. Another contribution was made by combining theory on uncertainty from different fields. This resulted in a rich and broad view on what makes the world uncertain.

First the literature study has been carried out. This theoretical research focused on two subjects: 1) uncertainty; and 2) planning. Thereby research questions 2, 6, 7, 8, and 9 were answered. This led to two products: 1) a descriptive framework for the case study analysis; and 2) normative notions about uncertainty analysis. With these frameworks research question number 1 was answered.
The descriptive framework was used to analyze four cases, which are comparable in respect to, among other things, magnitude and scale. Namely:

1. Project Infiltratie Maaskant (PIM) of Waterleidingmaatschappij Oost-Brabant (WOB);
2. Het Oever en Diepinfiltratie project (OEDI) of Waterleidingbedrijf Midden-Nederland (WMN);
3. The planning of production facility Jan Lagrand of PWN Waterleidingbedrijf Noord-Holland (PWN)
4. The Lek-duin and Maas-duin projects of Duinwaterbedrijf Zuid-Holland (DZH)

Thus research question number 3 was answered.

The case results were compared to each other and to the theoretical notions on what is a good way of analyzing uncertainty and dealing with it. This resulted in two products: 1) recommendations to drinking water companies on how to address uncertainty; and 2) recommendations on how to adapt theory to the findings. Thus questions number 4 and 5 were answerred. The results were evaluated with scientific experts and experts from the drinking water field. The last step consisted of a reflection on the research and the methods used and a generalization of the results. The research design is summarized in figure 1.1.

1. Theoretical research on uncertainty, and planning
   Resulting in: → Descriptive framework
   → Normative notions about uncertainty analysis

2. Case study analysis, using the descriptive framework
   Resulting in: → Findings on how drinking water companies actually deal with long term uncertainties

3. Comparison of case study results with normative notions and with each other
   Resulting in: → Recommendations to drinking water companies
   → Reflection on the theory used

4. Evaluation of the recommendations with experts from the drinking water practice
   Resulting in: → Evaluated recommendations on dealing with uncertainty

5. Reflection on all previous steps and on the used framework of analysis and generalization of the results
   Resulting in: → Reflective notions about the research

Figure 1.1 Research design

The empirical research was based on interviews, case study research, and a workshop with experts from the drinking water field. First interviews were used to get an impression on how uncertainty is dealt with in drinking water infrastructure planning. These results were used to choose the case study set-up in which cases were studied more in depth on how uncertainty is or has been dealt with in drinking water infrastructure planning.
The case study research was based on written sources about the cases and in-depth interviews and discussions about the case study findings with people that were involved in the projects that were studied. Thus it was made sure that enough different sources of evidence were used to base the final conclusions on, in this way the triangulation criterion has been met (Yin, 1994). The cases were studied ex-post. This type of case study research is suitable to study long term projects over an extended period of time. That way, not only the actions of a drinking water company could be observed but also the consequences of these actions.

1.4 Outline of the thesis

In chapter 2 the drinking water industry in the Netherlands is explored. Chapter 3 provides the theoretical backbone of the research. The term uncertainty will be related to similar concepts such as risk and related to topics like the use of models and decision-making under uncertainty. Also, the concept of planning is explored. Finally, in this chapter choices are made on which concepts from literature are explored further and which are not.
Then, in chapter 4, the concept of systems-thinking is explored. This was done because this concept proved to be very useful to describe the drinking water infrastructure and choices that were made with respect to this infrastructure and to relate these decisions to theoretical notions on dealing with uncertainty. Questions that are addressed are: What are systems, how

can they be modeled, and how are they designed? What are the specific characteristics of drinking water infrastructures in this respect?
Normative notions about the performance of an uncertainty analysis are described in chapter 5.
Subsequently, the empirical side of uncertainty analysis is investigated. In chapter 6, the case study set-up is described.

Then the various methods and techniques that are and were used in the drinking water industry to identify uncertainty and strategies to deal with these uncertainties were studied in cases (Chapters 7 to 10). In chapter 11 the overall case study results are presented.
The thesis ends with a reflexive and conclusive chapter 12. The practical ways of doing an uncertainty analysis are compared to each other and to the theoretical normative notions that were developed in chapter 5. The aim is to arrive at specific recommendations to drinking water companies to improve their way of doing uncertainty analysis and using this analysis in the design process, but also to make scientific contributions to theory on uncertainty analysis. Also, chapter 12 reflects critically on the theoretical framework that was used. Finally the results of the research are judged on the possibility of generalization towards other infrastructures, and a critical reflection on the research is provided.
The relationships among all these chapters is summarized in figure 1.4.

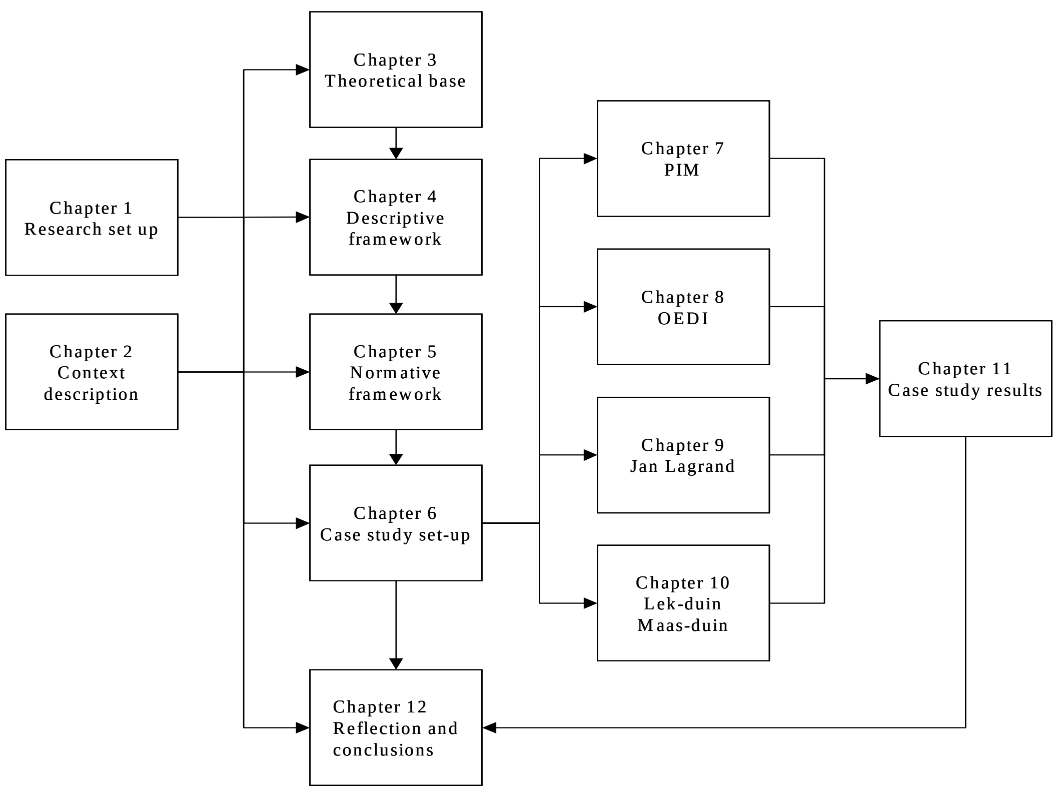

Figure 1.4 Relationships between the chapters of the thesis

Chapter 2 Drinking water systems in the Netherlands: planning and organization

What man desires is not knowledge but certainty.
Betrand Russell

In this chapter the planning and organization of the Dutch drinking water supply is described. This has been done to indicate both the specific character of drinking water infrastructure and the specific Dutch setting. The description in this chapter provides basic insight into the Dutch drinking water sector. The book 'Institutions for Water Resources Management in Europe (Correia ed., 1998) is suggested for further reading about the Dutch drinking water supply system and a comparison with the drinking water supply systems and institutions of four other European countries.

The central organization of drinking water supply has developed in the Netherlands over a period of more than hundred years, starting in the late 1800's. A cholera epidemic in 1866 led to the realization of public drinking water utilities and sewer systems. The current design of the Dutch drinking water infrastructure reflects the political climate and economic developments of the past 50 years. The infrastructure hardware is well maintained, but rates of replacement have been rather low in the past 30-50 years. Drinking water companies face major reconstruction of water distribution networks in the next 10-20 years.
In the Netherlands water is considered to be a public good and water services organizations in general belong to the public domain. The equity in access to water services is very high: 99% of the Dutch households are connected to water distribution networks and pay for water services. Customers in rural areas receive the same quality and type of services and products at the same price as those in densely populated urban areas.

Drinking water companies
Drinking water companies own and manage drinking water distribution networks and purification plants. Each of these companies holds a monopoly of delivering water in its service area. Recently the supply to large users (more then 100.000 m^3 per year) was liberalized. These users now can choose from which supplier they like to buy water. Usually, however, this will only be efficient to them when they are situated near the border of the service area of two companies, for distribution of water is the most expensive part of water supply.

Drinking water companies are owned by public stakeholders: cities and/or governmental agencies (provinces). There are few exceptions to this delegated public ownership: only one small company is privately owned, which soon is to be incorporated in a big public company.

Theoretically, every task in the water supply chain can be performed by a separate company. Most drinking water companies are responsible for the total chain of water harvesting, purification and distribution. There are however a few companies that concentrate on one or two of these tasks, like Waterwinningsbedrijf Brabantse Biesbosch (WBB). This company is owned by several drinking water companies and only harvests water and takes care of pre-purification of this raw water. This pre-purified water is not as pure as drinking water yet and is sold to drinking water companies or industries.

The Netherlands has approximately 15 drinking water companies. It is expected that this number will decrease in the near future as an effect of mergers. Most drinking water companies supply water as their core business. Some are multi-utilities, like for instance Delta, which also offers gas, electricity, cable television and internet services. These multi-utility companies, however, are exceptions. Because privatization of drinking water companies recently has been forbidden, it is harder for these companies to operate efficiently as a multi-utility in the international playing field.

Water harvesting and purification

About two thirds of Dutch inhabitants drink water prepared from groundwater supplies located in the northern, eastern and southern provinces. In the more populated western part of the country, drinking water is prepared from river water. In that part of the country, groundwater contains large amounts of chlorides because of its proximity to the North Sea.

Fresh water resources in the Netherlands are relatively large because of the inflow of transboundary, snow and rain-fed rivers. Water scarcity is not a large issue in the Netherlands with respect to drinking water supplies, but the deterioration of water quality in rivers and lakes has prompted water companies to use groundwater resources.

There is a variety of technology available for drinking water preparation, ranging from simple sand filtration for clean source water to chemical treatment or membrane technology for more polluted water. The use of chlorine to disinfect drinking water over the past years has been limited to the least possible. Often ozone is used as an alternative. Treatment sludge is incinerated because of its iron content, unless it has economic value for brick manufacturing.

Quality of purified drinking water can only be guaranteed when the dwelling time of the water in the distribution pipes is not too long. This fact, combined with the high transport cost of water causes drinking water infrastructure to have a regional character. The maximum distance from purification plant to water source is usually not further than 50 kilometer for economic reasons. Which makes the physical solution space for planning problems limited.

Water use

After a sharp increase in the period 1960-1980, the demand for water in the Netherlands has stabilized in the past decade in spite of population and economic growth (Figure 2.1). Household water consumption is decreasing because of the introduction of water saving appliances (mainly toilets and washing machines) and use of showers for personal hygiene rather than baths. In 1999 the mean water use per average household was approximately 130 cubic meters per year (VEWIN/Andersen Consulting, 1999).

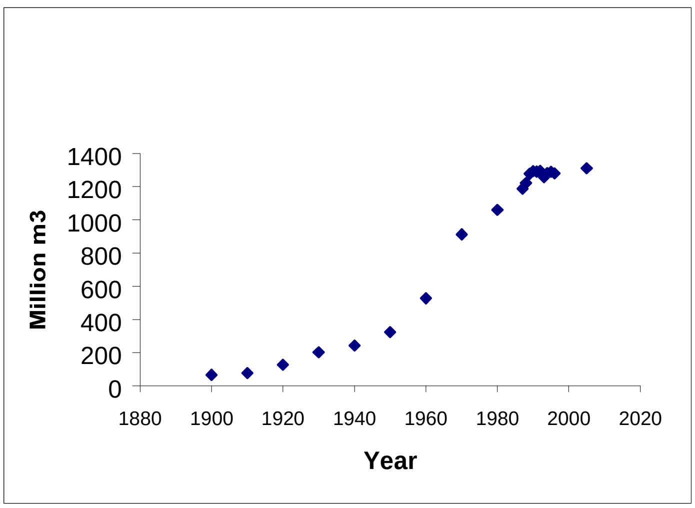

Figure 2.1 Production public water supply in the Netherlands (Adapted from: VEWIN, 1997)

Other important user groups beside households are large industries and farms. Industries use water in several different ways and the quality demands differ depending on the purpose of use: cleaning, cooling, or food and beverage preparation. For the latter purpose, water quality demands are much more stringent, sometimes even higher than for drinking water, as is the case for brewing. Drinking water supply companies can deliver these different products to industry, but some industries prepare water themselves from groundwater resources that they exploit.
Farmers usually need the most water in summertime, when total demand is at a top. In previous years it became popular to directly extract groundwater for farming purposes, as the cost was less than that of buying drinking water. This development is not considered desirable by national and regional water agencies because of aridification problems. Regulation is being developed on this subject.

Cost for consumers
Water prices for households range from one to two Euro per cubic meter, which is high compared to many industrialized countries with a similar quality service (Figure 2.2). The Dutch water price is determined on the principle of cost recovery and surcharged with a sales tax. This tax is 6 % as drinking water is considered a basic need. An increase to 17,5%, the tax rate for luxury goods, has been proposed by government as a measure to reduce water consumption further and protect water resources, but has not been effected.

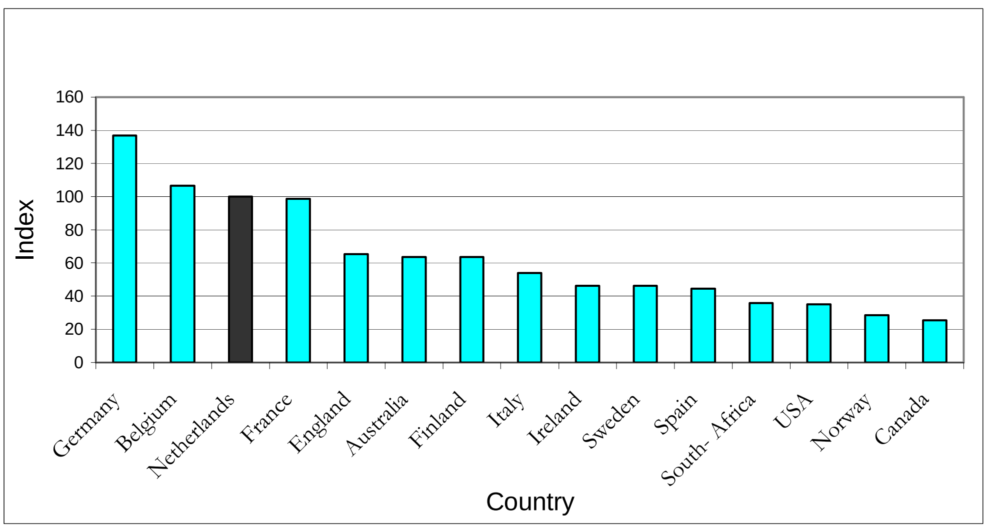

Figure 2.2 Price of drinking water per cubic meter for the Netherlands compared to other countries (Dijkgraaf et al., 1997).

Cost for water harvesting, purification and distribution are charged per cubic meter or, when water meters are not present, calculated per connection. A single person household pays more per cubic meter than households of more persons or larger users. This can be explained by a fixed basic tariff per connection and by the lower cubic meter price for large users. The rates per user group are equal for every user in a certain region. People that live in an old city center therefore also pay for investments that are made in new developments and people at distant connections are not charged more.

Regulation

The first reason for organizing public drinking water services is to secure public health. The Dutch government imposes strict rules, regarding the microbiological safety, pressure, taste, and color of drinking water. These requirements are formulated in the Drinking Water Decree that is part of the Dutch Water Works Act. The ministry of VROM (Housing, Spacial Planning, and Environment) has stated that: 'Public water supply should be guarantied in a sustainable way and serve public health and welfare, and prosperity of society (VROM, 1993)'. Drinking water companies therefore have the following mission: 'To uninterruptedly provide sufficient drinking water, under sufficient pressure and of a good and constant quality.' The Dutch Drinking Water Act also sets norms for ownership and management of water supply companies.

On the European level important regulation can be found in the European Water Framework and in the European Drinking Water Directive. In this act the chemical and ecological protection of the surface water is regulated.

Planning cycle of drinking water infrastructure in the Netherlands

Jonker (2000) describes how Dutch drinking water infrastructure planning works. Usually plans are made for the long-term, the mid-term and the short-term.

Long term plans are used to set goals for 25-30 years into the future. WMO (Waterleiding Maatschappij Overijssel) and WG (Waterbedrijf Gelderland) for instance made a long term plan as a part of their merger preparation process (WMO and WG, 2002). Mid-term and short term plans are then used to translate these plans into actions.

The mid-term plan is used as a guideline for the preparation of new investments and generally made once in ten years. Cost for this preparation is added to the total cost of these new investments. If a project is abandoned this cost is written off immediately. Otherwise it is written off during the entire economical life of the new infrastructure.

Up until 1990 the mid-term plans of drinking water companies were formalized in national 10-year plans by the ministry of VROM. Drinking water companies had to include investment plans in these 10-year plans, otherwise they could not be executed. The last update of these plans was made in 1993 (VROM, 1993). From that time on groundwater extraction permits were no longer the responsibility of the ministry of VROM, but that of individual Provinces. Therefore branch organization VEWIN (Vereniging van Exploitanten van Waterleidingbedrijven in Nederland) asked the minister to be freed from the obligation to update the 10-year plan. Since 1993, drinking water companies only make individual plans.

Mid-term plans are formulated as follows:

1. Forecasts of drinking water demand are made for each of the years within the ten year period. Predictions of local authorities on new housing or industrial developments and population growth are used as a basis for demand forecasts. Assumptions are made about the drinking water demand of the population, which is dependent on the use of water saving appliances, the size of families and the improvement of sanitary facilities through urban renovation projects. The demand of industries is estimated by multiplying current use by national growth factors, corrected for new developed industrial areas. These figures are combined with demand of neighboring drinking water companies to arrive at the total expected demand of drinking water in that year.
2. This forecast is followed-up, if it appears that capacity may be too limited, by identification of projects that can be developed to extend production capacity. These

projects will be assessed in respect to their economic and technical feasibility. Also it will be identified what the state is of the existing production facilities (legally and technically).

3. The demand prediction is combined with figures on the existing production capacity. New capacity is planned in such a way that there will always be an over-capacity of 10%. This over-capacity is needed to take care of climatological aspects and mistakes in the estimation of demand. Usually the surplus turns out to be more then 10%.
4. Calculations are made to make sure that the transportation infrastructure can deal with the expected water flows. If necessary newly to build transportation pipes are included in the 10-year plan.

A drinking water company also makes short term investments plans, for 4 to 5 years. These plans concern routine investments, the realization of new user connections, and the purchase of water meters, but also cash flows of individual projects (something is called a project when it has a considerable size and complexity) and projects that are in the decision-making pipeline. Every year the 4 or 5 year plans are revised. A longer period before revision than 5 years is not considered beneficial because of uncertainties.

This way of planning, until recently, was thought to be satisfying in the Netherlands. However, the last few years some downsides have been noted within the drinking water sector. Forecasts often do not match the events as they really take place. Trend analyses can only be made with large bandwidths, with the consequences for instance that it cannot be forecasted any longer whether consumption of drinking water will increase or decrease. This decreasing confidence in forecasts and the thought that it must be possible to better deal with uncertainty is reflected by the following citation from the WMO-WG long term plan (WMO and WG, 2002): 'The coming years we will keep monitoring the development of the demand for drinking water. We have noticed that the current prognosis of drinking water demand contains a lot of uncertainty, but we realize that forecasting never means certainty. We want to improve on the way we deal with these uncertainties.'

Chapter 3. Uncertainty, planning and decision-making; overview and focus

Every man takes the limits of his own field of vision for the limits of the world.
Arthur Schopenhauer, 1788-1860, German Philosopher

This chapter reports on a literature study that was done to explore different facets of uncertainty, dealing with uncertainty, decision-making under uncertainty, and planning under uncertainty. Different scientific fields have addressed these subjects usually approaching them from different angles. This chapter does not try to integrate all that is said and written about uncertainty, planning and design. What it does do is discuss literature on these subjects in such a way that choices can be made about which notions to include in the research and which can be left out to fit the limits of scope that were discussed in chapter one. In chapters four and five the choices that were made will be integrated into a descriptive and a normative framework.
In this chapter at first, the definition of uncertainty is discussed. Then, uncertainty in modeling is addressed. Decisions often are made on the basis of qualitative or quantitative models representing reality. In these models different sources of uncertainty can be recognized. These sources of uncertainty are discussed. The following topic is decision-making under uncertainty, which is followed by basic theoretical notions on planning and design. It is explored how these two subjects are connected. Finally choices regarding the theoretical notions on the subjects uncertainty, dealing with uncertainty, decision-making under uncertainty, and planning are presented.

3.1 Uncertainty literature

The literature body on uncertainty is very diverse. People from different scientific disciplines have studied the topic, for example from a mathematical, philosophical, policy analytic, economic, psychological or design engineering background. Morgan and Henrion (1990), for instance, focus on dealing with uncertainty in model-based quantitative risk and policy analysis. Hall (1980), adopting a classification of uncertainty by Friend and Jessop (1969) addresses human behavior in the light of uncertainty and the consequences for the outcome of decision-making processes. Corrêa (1994) provides an approach to managing un-planned changes in manufacturing systems. All these authors address 'dealing with uncertainty', but the theory they use and the contributions they make differ significantly not only with respect to scientific background, but also in respect to level of scale and object of study.

Theory about uncertainty and how to deal with it has been applied to numerous very different empirical subjects. For example a lot has been written on climate change (Van der Sluijs (1997), Klabbers et al. (1998), and Swart (1994)), but also a lot of research has been done done to improve company investment and financial policies (for instance Dixit and Pindyck (1994)).
Uncertainty is studied at different time scales, ranging from short term to long term. Some authors write about dealing with uncertainty about the present, for example about how to make decisions about sewer systems with Bayesian statistics, while not all system parameters are known exactly (Korving and Clemens, 2001), whereas others write about decades to come. Shell, for instance, is famous for it's development and use of scenario's and the making of visions for the future, as can be found in Schwartz (1991) and Shell (1998).
Moreover, uncertainties are classified in different ways, for instance according to source, type, probability and magnitudes of impact. Van der Sluijs (1997) provides an overview of such classifications by different authors, which easily could be extended further.

It is safe to say that there is no commonly agreed upon conceptual framework or approach to uncertainty classification. For example, van der Sluijs (1997) defines unreliability as a type of uncertainty, just like inexactness and ignorance. Rotmans (1999), however, defines unreliability as the result of inexactness, lack of measurements and practical measuring difficulty. It is unlikely that both authors mean exactly the same with the same words (see table 3.1 for an example).

Table 3.1 An example of differences in definitions of different authors on uncertainty classification.

van der Sluijs (1997)	Rotmans (1999)	
1. Inexactness 2. Unreliability 3. Ignorance	1. Inexactness 2. Lack of measurements 3. Practically immeasurable	1 t/m 3 together: **Unreliability**
	4. Conflicting evidence 5. Ignorance 6. Indeterminacy	4 t/m 6 together: **Structural/ systematic uncertainty**

Uncertainty researchers have noticed this problem. To address this problem, workshops have been organized which were attended by several authors from different scientific backgrounds on uncertainty theory, but until now this has not led (yet) to a shared framework of reference. An attempt was made by Walker et al. (2003) to create a shared framework of reference for model based uncertainty.

In this framework they distinguish three dimensions of uncertainty:

1. The *location* of uncertainty- where the uncertainty manifests itself within the model complex;
2. The *level* of uncertainty- where the uncertainty manifests itself along the spectrum between deterministic knowledge and total ignorance; and
3. The *nature* of uncertainty- whether the uncertainty is due to imperfection of our knowledge or is due to the inherent variability of the phenomena being described.

This framework, however, is not adopted (yet) by all uncertainty researchers, and is limited to model based uncertainty. Where possible, this thesis uses generally accepted definitions. However, when it comes to uncertainty itself these do not exist.

3.2 Defining uncertainty

Uncertainty exists about the past, the present, and becomes larger and larger in the future as the time-scale extends. For the present and the future this can be graphically represented by the 'trumpet of uncertainty' opening into a wide bell (Figure 3.1).

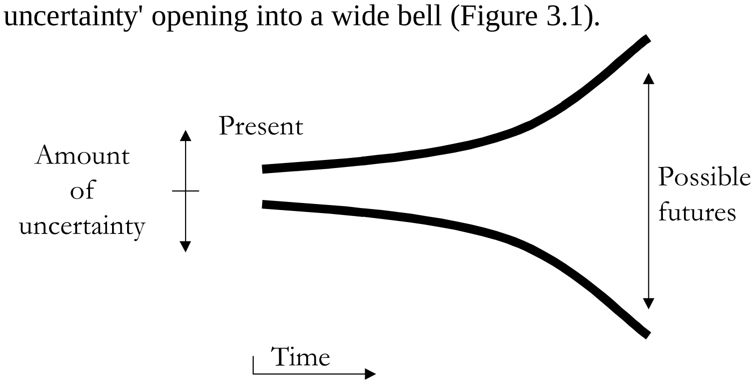

Figure 3.1. The trumpet of uncertainty (Rosenhead, 1989)

Before focusing on further choices it is important to make clear how we interpret the term 'Uncertainty'. The unknown characteristics of the future are often addressed with the terms: risk, uncertainty, indeterminacy, ignorance, the unknown, and the unknowable. We will make a clear distinction among these terms, and especially between uncertainty and risk, for these concepts are often used as synonyms.

The classical way to differentiate between uncertainty and risk is in terms of probability and outcomes. Knight (1921) for instance defines risk and uncertainty as follows: 'The practical difference between the two categories, [...], is that in the former the probability distribution of the outcome in a group of instances is known (either through calculation *a priori* or from statistics of past experience), while in the case of uncertainty probability distributions are not known, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique.' In other words: the distinction between risk and uncertainty is that the term ‘risk’ is used to indicate a situation in which the random event comes from a known probability distribution, whereas in a situation of uncertainty the probability distribution is unknown and must be chosen subjectively (Quade, 1989).

We define uncertainty as consisting of three levels next to certainty: risk, indeterminacy and the unknown. With this definition uncertainty is everything but certainty. Therefore an other word has been chosen to refer to what Knight and Quade, but also many other authors, such as Wynne (1992), define as uncertainty. What they define as uncertainty, we call *indeterminacy*. The unknown is introduced to refer to those situations of which the possibility of occurrence is not known. Consequently, beforehand no probabilities or consequences of outcomes of the events can be determined. This distinction is based on what is known about the distribution function of probability and consequences of events (see Rogers, 2001, for a similar categorization of uncertainty). An event is considered to be a happening, incident or series of circumstances that can or does cause changes in a system. We define certainty, risk, indeterminacy and the unknown the following way (see figure 3.2):

Certainty- A characteristic of an event that is known with respect to the exact time, place and consequences.

Risk- A characteristic of an event with known probability and consequences (Knight, 1921). Think about the breaking of a water distribution pipe.

Indeterminacy- A characteristic of an event of which either the probability, or the consequences, or both are not known. For instance it is not possible to determine the probability that drinking water companies will be privatized, and if so what the consequences of that will be.

The unknown- A characteristic of an event that is not imagined or anticipated. Or as Wynne (1992) says: "There is no way in which cause-effect relations of the future can be imagined". For instance no-one in the drinking water business would have thought in the 1960s that an oil crises was at hand and what impacts that would have on the performance of the companies.

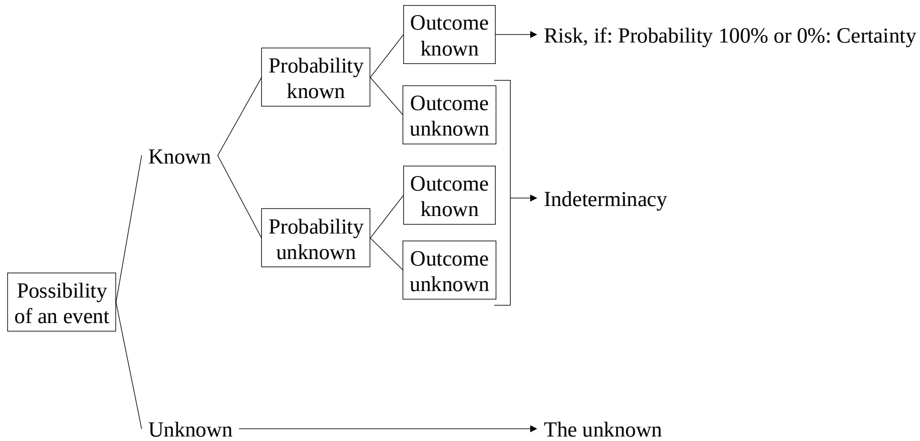

Figure 3.2. Uncertainty about future events

When this framework is compared to the framework of Walker et al. (2003), the term determinacy is used as we use the word certainty, the term statistical uncertainty is used where we use risk, scenario uncertainty and recognized ignorance are used where we use indeterminacy, and total ignorance is used where we use the word the unknown.

A term that also needs explanation is *'Ignorance'* as we use it here. Ignorance is an attribute of persons, i.e. the state of not being aware. Or as van der Sluijs (1997) defines it: We don't know what we don't know'. It is possible to be ignorant about something that is certain, for instance that it is someone's birthday. It is also possible to be ignorant about a risk, most people were ignorant of the risk of getting infected by Legionella bacteria until over thirty people in the Netherlands died from legionella-disease in 1999. Ignorance is a term that can be applicable to all categories of (un)certainty.

3.3 Uncertainty and the use of models

A model is a simplified representation of a real object or situation (Forgionne, 1986). To be able to tell more about the past, present, or the future, often models are used. Causal models are built up from knowledge about cause-effect relationships. Usually the model is based on data from the past. When making these (quantitative) models, three sources of uncertainty are of concern (Rahman, 1997):

- Uncertainty about *data* originates from not knowing whether the right data have been collected, that the data have been collected in the right way, or that not enough data have been collected, see Rahman (1997) and van der Sluijs (1997). An example of how uncertainty about data can have devastating consequences is the following: Up until ten years ago microbiological quality of drinking water was measured on the basis of indicator organisms. The outbreak of *Cryptosporidium* in Milwaukee (USA) in 1993 showed that this test did not provide information on all pathogen micro-organisms. 400.000 people fell ill after using drinking water that was infected by this coli-bacterium.
- Uncertainty about *model structure* is uncertainty about the model specification. In other words the uncertainties in the relations and descriptions used in the model (Vesely and Rasmuson (1984)). An example: How does a certain change in water quality (e.g. herbicide concentration) influence the purification processes?
- Uncertainty about *the structure of the system under consideration and the relationship with its environment* originates from a lack of understanding of certain phenomena (missing parts of the puzzle), but also from not fully predictable phenomena (See: Rahman, 1997). It is uncertainty about the effects of not fully predictable or not well

understood phenomena from outside or within the system on the system behavior. For example, new technology makes it possible to use surface water for the preparation of drinking water without much extra cost compared to ground water. Another example: the unforeseen planning of new housing projects in the service area significantly increases the demand on drinking water production.

These three sources of uncertainty in models are not necessarily independent of each other. It is possible, for instance, that the wrong model structure is chosen because the available data were insufficient to interpret relationships between variables correctly. It is also thinkable that important features of a system could not be identified because the structure of the model that was used to identify them did not include all relevant variables.
In a way the three sources of uncertainty are mutually dependent. Without a good theory about the system structure it is very difficult to construct a good model of that system, and to interpret the available data. Therefore, when dealing with uncertainty about the system structure indirectly a lot of uncertainty about data and the model structure is also dealt with.

These three sources of uncertainty can never be totally overcome. Uncertainty about the system structure is, often, for complex problems such as infrastructure planning problems, the largest source of uncertainty in an analysis, and the one with the largest consequences for decision-making (Rahman, 1997). Uncertainty about the system structure is the most difficult to handle. Uncertainty about the model structure can to a great extent be dealt with by doing a sensitivity analysis using different future values of explanatory variables. Uncertainty about data can be reduced by gathering more and better data. Despite the fact that uncertainty about the system structure has generally more impact, most research has been done in respect to uncertainty about data or the model structure (see for instance Beck, 1987; Functowicz and Ravetz, 1990; Helton, 1994; Morgan and Henrion, 1990).

In addition to the model uncertainties that were mentioned above, Walker et al. (2003) also distinguishes uncertainty about the *context* of a model, which is caused by the definition and the boundaries that were chosen for the model. These choices determine which part of the real world are modeled and which are outside of the model.

3.4 Uncertainty and decision-making

Decisions are made under uncertainty. These decisions can be made on different grounds, for example by minimizing the potential losses. In 3.4.1 different attitudes in decision making under uncertainty are explored..
Next to preferences of decision-makers in choosing strategies with more or less risk it is possible to develop strategies that can be adjusted when the future unfolds. In literature different suggestions are made to smartly handle uncertainty, like for instance assumption based planning and adaptive policy making (Dewar et al. (1993), and Dewar (2002)), trial en error, learning, etc.
Three of these suggestions will be discussed in further detail in this chapter. These are signposts (3.4.2), options (3.4.3), and hedging (3.4.4).

3.4.1 Attitudes in decision-making

When making decisions about which strategy to follow, the people making the decisions can have different attitudes towards how they take uncertainty and possible consequences of future developments into account. The following description of attitudes is based on Beroggi (1999). First, decision-makers can choose an alternative of which it is certain that its minimum utility is as high as possible. This attitude in literature is called the *MINMAX* attitude. This attitude avoids worst-case scenario's regardless of their chance of occurrence. Second, decision-makers can choose an alternative based on minimizing the maximum regret. This means that the maximum losses or missed gains that can result from a decision are minimized. This attitude in literature is called the *MINMAX regret* attitude. Third, decision-makers can have an attitude that combines the former two. For instance by weighing for each alternative the minimum and the maximum utility under different circumstances, or by calculating an average utility for each alternative under different scenario's. Note that the latter option does attribute the same probability to each possible scenario of what will happen in future. Schick (1997) provides an analysis of the ins and outs of each of these attitudes in decision-making.

Another basis for decision-making might be the MEV (Maximize Expected Value) attitude in which the maximum expected value of the different strategies is used as a basis for decision-making.

These theoretical notions are only applicable in situations in which enough is known (see figure 3.2). In most instances this is not the case: the theory of limits to rationality is applicable. This theory stipulates that people have only limited capacity to process information. Simon (1976) therefore rather speaks of searching for satisfying solutions rather than maximizing utility in choosing between alternatives.

Nevertheless, decision makers often do have a tendency to maximize utility or to minimize regret. Just think about the preference for robust solutions to problems. What attitude decision-makers have can be based on company policies and culture, personal preferences of the decision-makers, and the stakes involved in the decision. In this respect, the specific context of the problem situation and the relative size of the risk with respect to what an actor can bear can be of influence on how decisions are made. Garreth Morgan (1997) for instance mentions that persons make decisions based on the basis of their task, their personal characteristics and externalities. Kahneman and Tversky (1982) argue that people's shortcomings can be attributed to the lack of general intellectual skills, to a lack of specific substantive knowledge or to a failure to exploit their skills and knowledge adequately. Thus people may not know how to choose between possible ways of action.

3.4.2 Actions to handle uncertainty: Signposts

Monitoring is necessary to know what changes are occurring. Monitoring efforts become even more valuable when indicators of potential change are compared with the monitoring results. A signpost indicates when the course of things develops in such a way that further decisions or actions are necessary. Or more precisely, a signpost is an event or threshold that clearly indicates the changing vulnerability of an assumption (Dewar et al. (1993)).

Crucial assumptions are those assumptions that, if turning out to be false, have significant consequences for the outcome of an action. A timely recognition of a false assumption makes it possible to change the course of action that was decided upon before. Signposts therefore are assumption specific, but a single signpost may portend the violation of more than one assumption.

The monitoring activity thus involves the scanning for the specific events and thresholds that have been signposted. If these events happen or a threshold is reached a contingency plan can be effectuated. Therefore, signposts should be developed in direct conjunction with a further plan for action that can be used in case the signpost triggers for action.

Signposts preferably are unambiguous. It is, however, not always easy to establish such signposts. The assessment whether a signpost is reached may involve expert judgment about the significance of a signposted event or threshold.

Dewar (2002) identifies three ways of identifying and specifying signposts:

1. Using formal indicator systems. In this approach signposts are determined on the basis of a formal indicator system that is used to monitor some development. An example of a formal indicator system is the Index of Leading Economic Indicators. With this system the economic tide is monitored. For this index, three consecutive monthly changes in the same direction suggest a turning point in the economy, and thereby can be considered to be a signpost for a changing economy. For the purpose of signposting, generally a sufficiently long history of performance data is required.
2. Deriving signposts from aimpoints. Aimpoints are measures of a plan's success or failure. Signposts can be derived from such aims. For instance, a drinking water facility that can be built in two modules is designed to deliver 20 thousand m^3 per year from the fifth year of operation when it is completely finished. The plan is to build the second module three years later than the first. A possible signpost in this case would be a delivery of 10 thousand m^3 in the second year of operation. When this amount is not sold this is a sign to reconsider the installation of the second module in the third year.
3. Common-sense way of proceeding. This approach starts with the vulnerability of an assumption. Consecutively, a path along which the assumption could fail is imagined. Around that path one looks for unique, unmistakable identifiers of that path. These are the signposts.

3.4.3 Actions to handle uncertainty: options

Particularly for capital intensive infrastructure decisions, it is most important to have some way of coping with future changes. 'Options' is a generic term that is used to indicate those aspects that have been included in a planning and decision-making process that make sure that the solutions resulting from this process are flexible, adaptable, robust or reversible (being able to return to the original state of the system). When a plan or a design for some physical asset is concerned, often the term 'real-option' is used. In this thesis the term options is used in a broad sense, including both 'real options', and the investments in knowledge and time that enable postponement of decision-making.

Option theory has its roots in the financial world. The Nobel-price winning work of Black, Merton and Scholes made it possible to calculate the value of options (Dixit and Pindyck, 1993). Practical examples for the use of 'real' options can be found in Amran and Kulatilaka (1999), Neely and de Neufville (2001, de Neufville (2000) and 2001). In applying the real-option approach to strategic decision making, some caution should be taken, because it is debatable whether values of options can always be calculated. Some cost and benefits of using options cannot be expressed in monetary values. This is definitely true for the benefits of drinking water supply to society (e.g public health) or cost of water resources exploitation (e.g. damage to nature).

Different authors mention different types of options. Amran and Kulatilaka (1999) for instance distinguish 'waiting-to-invest' options, 'growth' options, 'flexibility' options, 'exit' options, and 'learning' options. Quade (1989) mentions 'buying time', 'buying flexibility', 'taking the conservative approach', and 'buying information'. By combining these lists, and others like it, the following four option strategies have been identified:

1. Investing in time
2. Investing in flexibility (special forms: investing in reversibility, investing in exit possibilities)
3. Investing in robustness

4. Investing in knowledge: 1) About the present- Learning in order to know a situation better; and 2) For the future- Research and Development

In this list many possible future related tactics are consoled. The term options in this thesis thus is used to indicate a broad set of uncertainty related tactics, both offensive like investing in robustness and defensive like incorporating flexible parts in a design or research and development to be able to grasp opportunities as they arise.

The following paragraphs will discuss these four types of options.

1. *Investing in time*

Investing in time by delaying decisions has the advantage that some uncertainties disappear in the course of time. Events that were predicted but were not certain in respect to time, place or consequences may have happened; the probability distribution of indeterminacies and possible impacts may have become known; and events that were unknowable may have become indeterminacies. Quade (1989) calls the strategy of postponing decisions 'buying time', for postponement of a decision usually bears a (non-monetary) cost. Not all decisions can be delayed. Sometimes it is better to just act immediately, because of the price attached to postponement or because it is a matter of 'now or never'.

De Bruijn, ten Heuvelhof and in 't Veld (2002) state that actors may associate every decision as a trap, which indicates a point of no return. Offering room by delaying a decision may benefit the progress and the quality of the eventual outcomes of a decision process, because decisions are taken in a more relaxed atmosphere. They also mention that the postponement of commitment furthers learning processes. During the process, new insights will become available, facts turn out to be different from what they are often thought to be and even normative views can change. Such a learning process can be seriously blocked if binding statements are made at an early stage. Miller and Lessard (2000) remark that actors cannot remain flexible indefinitely: eventually cascades of moves must be made. The art is in committing at the right time.

2. *Investing in flexibility*

According to Corrêa (1994) the flexibility of a system can be defined as the ability to deal effectively with the effects of unexpected developments, as these effects are experienced by the system. This definition is adopted with the annotation that this ability to deal with changes is characterized by limited loss of time, effort, cost, or performance of dealing with that change (Meijer and Ruijgh-van de Ploeg, 2001). Flexibility of a design can be pursued in different ways. One design possibility is to make use of components and materials that can be replaced and disposed of easily and affordably. Another option is to build in modules rather than to build one large system based on uncertain assumptions about future demand for capacity. A third option is to design a system that can be used for other than the original purposes also. Flexibility can contribute to robustness of the design (see following paragraph).

A particular form of this type of option is investing in reversibility. Reversibility is the degree to which it is possible to return to conditions that existed before a change, if that change does not work out (Walker et al., 1979). When a strategy is implemented involving a complete change of a system, a part of this strategy may involve the possibility to switch back to the old system in case the new system does not function properly. In the same way the 'exit' option, mentioned by Amran and Kulatilaka (1999) can be understood: it is the option to halt or stop a project without major losses.

3. *Investing in robustness*

Both flexibility and robustness of a physical infrastructure aim at expanding the number of future system environments in which system performance can be upheld. Both strategies increase the number of possible futures that can be dealt with, but use a significantly different approach to reach this goal. In aiming for robustness, a specific design is meant to be suitable for several futures without changing it. Tactics aiming for flexibility lead to a design that can be altered and adjusted in the future according to the changing needs.

Robustness is the degree to which a design can succeed in a wide range of future environments (see for example Arguden, 1982). Robustness can be achieved in different ways. The ultimate goal is to have infrastructures that are not likely to fail in changed circumstances. In the case of water infrastructure, the use of inert, lasting materials and over-dimensioning of the filtration, transportation or storage capacity are well-known 'robust' design principles to expand the number of futures for which the design is suited.

Similarities between flexibility and robustness

Robustness and flexibility can both be sought at different levels within an organization or planning process. It is for instance possible to invest in a robust hardware part of the infrastructure, but it is also possible to develop a robust company financial plan (in which case the system boundaries have been placed around a companies financial structure). In this respect *investing in insurance or sharing responsibility with different stakeholders* can be seen as investing in the robustness of the companies financial or legal position. Also, flexibility can be built into a planning process. For instance by designing the process in such a way that new insights can be introduced into the decision-making without the process being frustrated. An approach to decision-making that is developed with this idea in mind is the living document approach (van der Most, Koppenjan en Bots (1998), and Enserink and Monnikhof (2003). All are examples of investing in robustness and flexibility, but they aim at robustness or flexibility in totally different outcomes of interest of a company.

The strategies aiming for flexibility and robustness can both lead to what Quade (1989) calls the 'conservative approach'. Here the decision-maker attempts to choose the alternative that gives the best result if the environment is maximally mean to him. In other words, he resolves uncertainties by making the blanket assumption that the worst will happen. Alternatives that stem from this approach can turn out to be very expensive, when the future does not turn out to be so mean. Another argument against preparedness at all cost comes from Teisberg (1993). She notices that pursuing a robust strategy can undermine a company's chance for superior profits by forcing managers to avoid risky commitments with potentially high payoffs.

This research focuses on the planning process of physical drinking water infrastructure with respect to dealing with long term uncertainty. Therefore, especially those flexibility and robustness options that concern the performance of the physical infrastructure on the long term will be investigated.

4. *Investing in knowledge*

A very different approach to dealing with uncertainty is to conduct research, pay others to do research, or stimulate or persuade others to do research. There are two types of investing in knowledge, i.e. Investing in knowledge about the present and investing in knowledge for the future. Quade (1989) would call the investing in knowledge options 'buying information'.

Strictly speaking it is not really an option to invest in knowledge, but it is a tactic to reduce uncertainty and identify possible future ways of action.

The first type, *investing in knowledge about the present*, aims at the gathering of more and better knowledge about how the system functions under present circumstances. This strategy does not only concern research on technical issues, but for instance also on institutional, economic or social issues. It is important to keep in mind that more knowledge does not necessarily mean less uncertainty (Rotmans, 1999). More knowledge may cause people to realize that there are more uncertainties than were considered before.

The second type, i*nvesting in knowledge for the future*, is based on the same idea as investing in knowledge about the present. In contrast, this tactic aims at investigation of *future* possibilities, and new future possibilities that are yet unknown may be identified.

3.4.3 Actions to handle uncertainty: hedging

A term that is often used in respect to decision-making under uncertainty is hedging. Hedging tactics are those tactics that enable a person or organization to deal with a world beyond its control. More specifically, these are actions to be taken in the present and that are intended to better prepare for failure of an important assumption (Dewar et al., 1993).

Hedging actions and options are closely related concepts, but are not totally the same. We consider hedging actions to be a subset of options. Options include more actions than hedging. This is the reason why in this thesis the term hedging is not used further. Some types of options, like investing in robustness and flexibility when built into a strategy, can be considered as being classic hedging actions. Investing in knowledge can be considered to be a tactic that enables hedging actions in the future, but is not a hedging action in itself. Investing in time can be considered as an investment done to be able not to act, and therefore can be considered to be an option, but cannot be considered to be a hedging action.

3.5 Planning

This research focuses on the way in which the planning of drinking water infrastructure can be improved with respect to dealing with uncertainty. The goal is to arrive at recommendations for improvement without losing the clear benefits that are embedded in the current way of planning. Therefore it is necessary to explore the planning process more into depth. This is done by looking at life cycle theory, the differences and similarities with design processes and finally at the link with dealing with uncertainty. But first planning is defined as it is used in this thesis.

Planning is the guidance of future action (Forester, 1989). Planning in the drinking water world thereby is the process of strategic, tactical and operational decision-making about drinking water infrastructure (parts) in a time perspective. The planning process includes among other things long term, mid-term and short term investment decisions and embodiment of those investment decisions in the form of choosing from specific alternatives.
A term that is often used to point out a part of the planning process of infrastructures is asset management. Asset management is the field of knowledge oriented to the whole of actions that a person or organization takes in the life span of his, her or its assets. Asset management includes all those strategic and tactical decisions and actions about assets that originate from a desire to improve on the degree to which business values are met (Townsend, 1998). Asset management is usually not meant for planning of large investments, but rather for the planning of maintenance or replacement of infrastructure that already exists.

Asset management is a term that becomes more and more popular. Dutch, but also foreign, infrastructure managers, see it as a way to work more cost effectively without losing quality of service. Usually computer applications are used to support these managers in making investment decisions for the short and mid-term. These investment decisions often will be about the choice for replacement of infrastructure parts or maintenance of the existing parts. It is important to notice that asset management potentially is more than these computer applications! However, some people use the term just to address the use of such applications.
In the remainder of this thesis asset management will not be mentioned further. This has two reasons: 1) Dealing with uncertainty in drinking water infrastructure planning processes is the central issue in this thesis, using it in the same sense as the term asset management would be confusing; 2) Since the term asset management is becoming more used, people all have their own ideas about what asset management is and is not.

3.5.1 Life cycles and planning processes

The ultimate goal within any planning process for drinking water infrastructure, either short term, mid term or long term, is an infrastructure (part) that is functioning as well as possible over the total period for which it is planned. Planning decisions influence the way in which the infrastructure can deal with future changes, either originating from sources outside the control of the infrastructure managers, or originating from changing preferences about performance of the infrastructure. To make these decisions properly, the total lifecycle of the infrastructure part that is planned for will have to be taken in consideration. It is for instance of crucial importance to consider maintenance or retirement issues from the start of the planning of a new infrastructure part.
An infrastructure part goes through a life cycle. In literature, lists can be found that divide the lifecycle in 5 to 9 phases. For instance Cleland and King (1983) mention the following 5 phases which are identified by the U.S. Air Force: 1) The conceptual phase; 2) The validation phase; 3) The full scale development phase; 4) The production phase; and 5) The deployment phase. Each of these phases consists of several sub-phases. Some authors therefore have longer lists than others depending on the sub-division that they have chosen. After studying different possible divisions (French (1985), Cleland and King (1983), Roozenburg and Eekels (1995), Bahill et al. (1998), Pugh (1986)) we concluded that on average the following phases can be discovered:

1. Discovering of system requirements
2. Concept exploration
3. Full-scale engineering design
4. Manufacturing
5. System integration and test
6. Operation and maintenance
7. Retirement, disposal and replacement

The difference with some other authors with longer lists is that they define some feedback-loops between the phases as being separate phases, where in this list the feedback-loops are assumed between all phases. The difference with shorter lists is a more detailed description of the phases after manufacturing, e.g. some authors include a testing phase and end the list with the use of the product, while others include a retirement phase as the final phase.

Planning can concern each of the phases of the life cycle. It is for instance possible to plan for the full-scale engineering phase, but also for the manufacturing process or the retirement of infrastructure parts. A planning process can concern one or more of the phases in a life cycle. Before an infrastructure part is completely retired, pieces of it may have gone repeatedly

through these phases. Iterations between the phases are possible, for instance because parts of an infrastructure are re-designed.
The goal of all planning activities is to get an infrastructure that functions as well as possible within certain constraints, such as available funds and planning time. Another goal is to be as efficient as possible in this strive for functionality. Unnecessary cost and early obsolescence are unwanted (Iselin and Lemer, 1993).
There are two points in an infrastructures life cycle where decisions are made of strategic importance to the system architecture and thereby to its functionality in its further life. First, when a completely new infrastructure part is set up. Second, when existing infrastructure (partly) is replaced. It is at exactly these points that this thesis focuses.

When a decision has to be made in a planning process more or less the following phases are made with respect to the content of the decisions (Forgionne, 1986):

1. Observe reality
2. Recognize a problem (or opportunity)
3. Identify alternative courses of action
4. Establish evaluation criteria
5. Evaluate alternatives
6. Choose the most preferable alternative
7. Implement the choice

Usually these phases are followed by an evaluation of the choice as it was made. Other authors present similar lists (for instance Walker (2000), or Rosenthal, Van Schendelen and Ringeling (1987)), but these don't differ much. The list is the same for different types of planning activities, ranging from budgeting to the planning of the implementation of a certain piece of infrastructure.
In a planning process, these phases can iteratively be repeated for the same decision that has to be made, but obviously within a planning process more than one decision can be made which all have the same set up.

3.5.2 The link between planning and design

A design process is a process in which a description of a technical system is developed in such a way that it will fulfill a number of requirements. Obviously, the design process and the planning process are very closely linked. In fact, a design process in itself is a special form of planning, namely the planning of the lay-out of a certain piece of technology, in this case infrastructure. The starting point of any design process is a description of requirements (Jones, 1982). Usually the requirements are for a large part determined in a planning process in which decisions of strategic nature are taken. Other requirements stem from governmental rules and regulations, consumer preferences or are translations of generic requirements into more practical terms.
French (1985) distinguishes four activities in a design process. These activities are: 1) The analysis of a problem, resulting in a problem statement; 2) A conceptual design, resulting in a selection of schemes; 3) The embodiment of the selected schemes; and 4) Detailing of these schemes, which eventually leads to working drawings etc. Other authors present similar lists, like for instance Hubka and Eder (1992), Roozenburg and Eekels (1985) and Pugh (1991). These last two authors independently argue, that the different design procedures that can be found in literature do not principally differ from each other (Roozenburg and Eekels (1985) and Pugh (1986)). In this thesis their opinion is shared.
The design activities as identified by French and others are logically the same as the three first phases of the life cycle of an object as was presented in paragraph 3.5.1. Therefore in this

thesis the phases of the life cycle as discussed in paragraph 3.5.1 will be used as a framework for addressing design activities.

When literature about planning and design is studied, similarities between the two are striking. Leach (2002), for instance, identifies a list of requirements of a good project plan, which is quite similar to the requirements of a good design process, for instance as stated by French (1985). Also, the set-up of a decision in a planning process as was discussed in paragraph 3.5.1 is basically the same as the phases in a design process as they were presented in this paragraph. The difference between the two is not as much the set-up and the requirements of both processes, but the fact that planning is often associated with projects, and design with objects.
It is hard to say when planning stops and design begins, especially when a new infrastructure is being realized or when an infrastructure part is being replaced. Both processes cannot exist without each other. By rule, decisions of high strategic importance are taken in the planning process, but the reason that these decisions are on the agenda can originate in the design process. Therefore feedback loops between the two processes are more rule than exception (see figure 3.3).

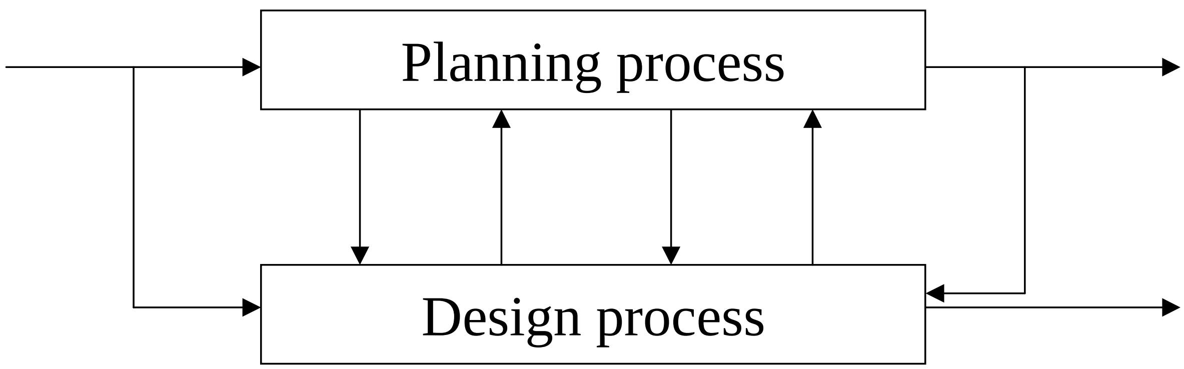

Figure 3.3 Interaction between planning and design processes.

The separation between the two processes in practice is not strict. Often the same people participate in both processes. Especially in the Dutch drinking water sector where management tasks are often performed by skilled engineers with a large knowledge of and interest in design issues and where the organization structure in general is not very hierarchical.

The planning and design processes are very closely linked, especially in the first three phases of the life-cycle of a new or replaced infrastructure part. These three phases are, by nature, preceded by a phase in which the awareness rises that a new infrastructure part should be developed or that re-design of an existing infrastructure part is necessary.
In these phases, design and planning go hand in hand. Because of this intertwinement, terminology of both disciplines can be used in coherence to describe the combined planning, and design activities for the development or replacement of an infrastructure part. The resulting four phases can be specified further as follows:

1. Awareness of a problem
   In this step the design/ planning problem is specified and a first identification of possible alternatives is made. This step results in a problem statement and a project description.
2. Discovering system requirements

To discover system requirements an identification of stakeholder interests and opinions is made. Also objectives and criteria of the planning or design process are identified and system boundaries are defined which determine the solution space and the scope of the planning or design process. An uncertainty analysis should be performed, because insight in uncertainties in the first stage of a project makes it more easy to plan for these uncertainties. Results of this step are a requirements specification and analysis.

3. Concept exploration: Functional system specification
   In this step a set-up of the actual plan or design is made. This means system specification and the selection of alternatives. This step results in a conceptual design.
4. Full scale engineering design
   The design process then continues with the development of a full scale engineering design, in which alternatives are embodied and detailed, which results in a system description which can be implemented.

This thesis focuses mainly on the second step in planning/design processes in which system requirements are discovered, system boundaries are set and uncertainty is studied. The consequences of choices in this step in dealing with uncertainty are examined for the following phases of the planning or design process. Also the consequences for the other four phases of the life cycle are studied, since the uncertainties that are dealt with in the first three phases all concern the functioning of the infrastructure in later phases. The latter four phases are, however, not studied themselves in detail.
Wherever in the remainder of this thesis the word planning is used the reader has to keep in mind that this broad perspective on planning is used, in which technical design questions can play a large role. This enriches the analysis and does not cause analytical problems since the same framework can be used to study both planning and design questions.

3.6 Focus in research

This research is limited to a specific body of literature. In the remainder of this chapter the specific body of literature that is used is pointed out. The selection of (parts of) theoretical concepts is based on the following criteria:

- The selected theoretical concepts must be usable to analyze planning processes and the choices that are made within them.
- The framework that is formed by using the concepts and its resulting conclusions is communicable to designers of drinking water infrastructure in practice.
- The framework that is formed by using the concepts can provide a basis for scientific contributions to uncertainty theory, either in practical or theoretical sense, preferably both.

This research combines notions from the different disciplines. Using theory from different scientific domains has a clear value. There is no single theory that combines all aspects of dealing with uncertainty or is specifically focussed on planning of infrastructures with respect to uncertainty about the future. The use of different 'lenses' to look through at the same phenomena assures that a rich picture can be made. In this way the core of each theory remains firm, but at the same time the blind-spots of each theory can be covered or highlighted. The strong points of each theory thus are preserved, while weaker elements get strengthened.

The remainder of the chapter focuses on how the choices for certain lines of thought were made. One by one, possible ways of focusing will be highlighted and the choices in this are explained. These choices have been grouped together by the same subjects that have been explored in this chapter: the definition and lines of thought on uncertainty, uncertainty and modeling, uncertainty and decision-making and planning and design.

3.6.1 Focus in respect to uncertainty

A practical and rational approach in dealing with uncertainty rather than a philosophical approach In this thesis we limit ourselves to a short discussion of the main movements that have preceded recent uncertainty thinking, in order to explain how this research is positioned in a philosophical sense. Uncertainty thinking as we know it has its roots in the enlightenment movement. In the period of enlightenment all phenomena were considered to be (scientifically) explainable. This way of thinking is called 'Positivism'. The first protests against this way of thinking came from mathematicians, when it appeared that different well-accepted theories didn't support each other and could have different results as a consequence. These kind of observations in the beginning of the 20th century led to two anti-positivism movements: Post-Modernism (originated in philosophical thinking) and Social-Constructivism (originated from sociological studies of science and technology). The most important messages of these movements were (van Asselt, 2000):

- Science is not a purely objective, value free activity of discovery: science is a creative process in which social and individual values interfere with observation, analysis and interpretation.
- Knowledge is not equivalent to truth and certainty.

This thesis is to a great extent positivistic in nature, but has also some anti-positivistic characteristics. On one hand a rational approach to deal with those uncertainties that can be dealt with is the basis of analysis. On the other hand it is appreciated that not everything is knowable and explainable.

Uncertainty about the long term rather than short term uncertainty When planning for the future it is necessary to look at possible future developments. This should be done from well founded ideas about what the future might bring. In this research, uncertainty about long term developments will take a central place. Long term, for drinking water provision systems, is defined as a period of twenty years or longer. In addition, uncertainty about those midterm developments that can change the outcome of a planning process is incorporated in the research. Midterm is defined as a period of 5 to 20 years. Uncertainties about short term developments (for a period of 0 to 5 years) are not examined further. Therefore the theory that is used in this research will focus on the identification of and dealing with uncertainty about long and midterm developments.

Indeterminacy and the unknown rather than risk Risks seem to be pretty well covered by drinking water companies. They have calamity plans at hand that can provide the people with enough drinking water in case of an emergency. Also they usually build vulnerable infrastructure parts like pumps and distribution pipes in pairs, so that if one fails the other one can take over. For this reason, most companies also have a connection with the infrastructure of neighboring companies. This redundancy thinking has grown over time. This development can be very well seen in Flevoland, a newly built Dutch province in the IJsselmeer, that has been reclaimed halfway the twentieth century. The first large city that was built there was Lelystad, the second Almere. In Almere the principles of ring distribution have been followed from the beginning. Lelystad's distribution system has more star like characteristics.

Because risks are well covered, it is much more interesting for drinking water companies to learn more on how to deal with the indeterminacy and the unknowable. Therefore this research will focus on these uncertainties. Another reason for this choice is that the knowledge base on risks in general is far more extensive than that on indeterminacy.

This research focuses on methods to bring uncertainty to the surface and to handle these uncertainties. Many authors like Morgan and Henrion (1990) put much emphasis on the topic of reducing uncertainty, usually in respect to the use of quantitative models. The argument behind this is that when more is known, better decisions can be made. For this thesis the choice was made not to focus on reducing uncertainty, but rather on handling uncertainty. This choice must be seen in the light of the choice to study uncertainty about the future. The further into the future one looks, the more uncertainty is irreducible. This large amount of uncertainty must be dealt with.

3.6.2 Focus with respect to uncertainty and the use of models

System rather than system components. System approaches can be followed in two ways; first a black-box approach, and second an approach that focuses on the inner structure and mechanisms of the system. In a black-box approach, system components are not further identified. In the other case the specification of system details takes a central place. This research focuses on the step of a planning process in which system requirements are formulated. For this phase it is not necessary to take detailed system aspects into consideration. On the other hand, a total black-box approach takes us too far, since then even company processes on the most abstract level are not further defined. In this research, the infrastructure system will be considered as a black-box, but where opening the black-box is necessary for clarification purposes, this will be done.

Uncertainty about the structure of the system and it's environment rather than uncertainty about data or model structure The focus in this thesis is on uncertainties about the system structure and it's surroundings for three reasons.

1. Research on uncertainties historically has been concentrated on uncertainty about data and the model structure. Research about the system structure needs more attention.
2. Uncertainties about the system structure are very difficult to deal with and good methods are needed to improve planning in relation to this source of uncertainty.
3. Tools to deal with uncertainties about the system structure can also be applied to uncertainties about data or the model structure.

3.6.4 Focus with respect to uncertainty and decision-making

Decision-making of organizations rather than individual or group decision-making Decisions about large infrastructure projects have to be viewed as decisions of organizations. Naturally individuals and groups within an organization will play a great role in these decisions. In spite of that, the focus in research will be on the outcome of the organizational decision-making process rather than on how this outcome was influenced by individuals or groups. This has been done for practical reasons. The line of reasoning of a company's process can be retrieved from official documents. Individual influences on this can not be found easily in retrospect.

Why decisions are made as they are made: Rationalization of decisions on the basis of facts, company values and assumptions rather than decision-making as a result of individual preferences and political games. It would have been nice if both would have been possible. But considering the time span of the type of projects under consideration, it is not possible to study such a project as it develops. It was a choice between studying a whole project and its consequences or just a part of it without being able to study its results. For reasons of being able to also see the consequences of decisions, the choice was made to study a whole project. This meant looking at case studies sometimes far in retrospect. Because of this choice a lot of information about underlying (political) motivations could not be retrieved. An extensive part of the framework for research that is presented in chapters 4 and 5 is based on the ideas of Dewar (2002).

Mono-actor perspective and the strategy of a public actor rather than a multi-actor perspective on strategy formulation The planning process of drinking water infrastructure takes a central place in this research. Obviously, a drinking water company will reason in this process from its own point of view. The network of other stakeholders is important in the sense that they can influence the decisions of the drinking water company and the functioning of the company. In other words they can be a cause of uncertainty. In this research these influences will be taken into consideration as external influences. As a logical consequence this research has a mono-actor perspective.

3.6.3 Focus with respect to planning

Planning/ decision making processes rather than modeling processes The purpose of the planning process of drinking water infrastructure is in the first place to decide on what the infrastructure will look like in the future. That is decision-making and conceptualization on main issues. The focus in research is on the improvement of the planning process with respect to long and midterm uncertainties. The modeling process is a part of the planning process but is not studied in more detail than other parts of the planning process.

Focus of the first few strategic steps of the life cycle Handling uncertainty is important in the whole life cycle. However, the first few steps of a planning process are the most critical. These steps are taken after the recognition that a new infrastructure (part) needs to be set-up or that an existing infrastructure (part) needs to be replaced.

3.7 Final remarks

Table 3.2 summarizes the choices that were made. Based on those choices a theoretical framework was developed that fits all the elements that were chosen.

Table 3.2 Choices for perspectives to include in the theoretical framework

Perspectives that were chosen	Perspectives that were not chosen
Rational and practical	Philosophical
Long term uncertainty	Short term uncertainty
Indeterminacy and the unknown	Risk
Handling uncertainty in a broad sense	Reducing uncertainty in a narrow sense
System as a whole	System components
Uncertainty about the structure of a system	Uncertainty about data or system components
Mono-actor in multi-actor setting	Multi-actor in a network perspective
Organization	Individuals and groups
Rational decision-making	Politics and games
Planning and decision-making on main issues	Modeling specific elements within the decision-making process
First strategic steps of the life cycle	The whole life cycle

A systems approach fits well within the boundaries in research that have been set in this chapter. The focus has been put on dealing with long term uncertainty with respect to the planning of drinking water infrastructures. The object of planning, the drinking water infrastructure, can very well be considered as being a system that can be influenced by the drinking water company itself or by forces from outside the system.

Capriciousness of actors other than the drinking water company itself can be represented in a systems approach as influences from outside the system on the system. Uncertainties can be sought either inside the system, in the influences on the system, or in the possible consequences of changes both inside and outside the system.

A systems approach accommodates the conceptual modeling of influences, decisions and the consequences of both over time, as well as quantification where feasible.

The advantage of a systems approach is that it can capture the essence of rational decision-making in a relatively simple scheme that can be communicated well to people with either a scientific or practical background.

The systems approach as was used in this research is presented and explained in chapter 4.

Chapter 4. A systems approach to planning: introducing the descriptive framework

I think it almost unlikely that aeronautics will ever be able to exercise a decisive influence in travel. Man is not an albatross.
H.G. Wells, the Discovery of the Future (1901).

A systems approach enables the description of the key substantive aspects of infrastructure planning for the future. Concretely, this means the description of the system under consideration, those influences that may cause future changes of system performance, the outcomes of interest to an organization with respect to system performance and the tactics or strategies of this organization. A systems approach can be used for the description of both the present state of the system and the system as it is preferred, feared, or might become in future. Thus the determination is possible of the gap between desired and actual or feared future performance of the system. This makes a systems approach very useful as a basic rational framework in the process of dealing with uncertainty, since the description and comparison is possible of all crucial elements in dealing with uncertainty from the perspective that was chosen in chapter three.

The structure of this chapter is as follows. First, the descriptive framework is introduced, which is based on a systems diagram. Second, each term that is used in the framework is explained and specified. Dutch drinking water issues in the 1990's are used as a returning illustration of each of the terms. Finally, the uncertainties that can be identified with the framework will be discussed.

4.1 Systems approach

Analysis of and communication about systems can be supported with a systems approach. A basic input-output systems model as is often used in modeling is a useful tool for a systems approach. In such as model the outputs of a system are seen as resulting from the combination of external inputs to a system and internal system properties (see figure 4.1).

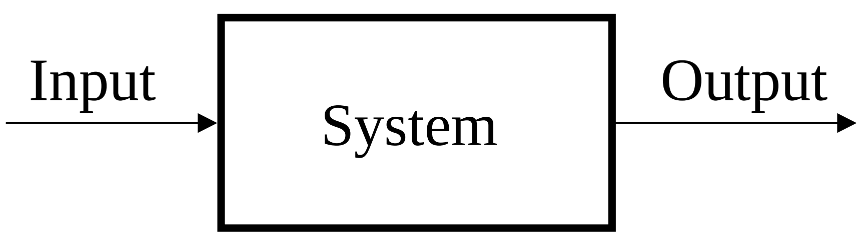

Figure 4.1. Basic input-output systems model.

A systems diagram can be very well used for the structuring and analysis of problems and decision situations. Sage and Armstrong (2000) use this model to describe the effects of future changes and tactics on a system. This conceptual model (see figure 4.2) distinguishes:

1. A system and its boundaries, for instance a drinking water distribution system;
2. The system output, which represents the outcomes of interest to a stakeholder, for instance a drinking water company, with regard to the functioning of the system;

3. The external inputs into the system that are not under the control of the decision-maker, often called driving forces from outside the system that can influence the system and its performance;
4. The intentional input from system designers and decision-makers in the form of a system design or system management, which are referred to in this thesis as strategies or tactics.

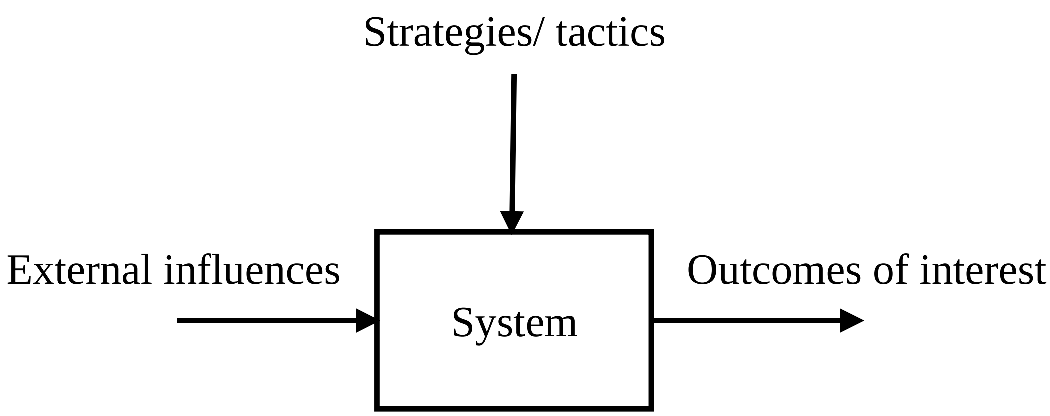

Figure 4.2. Input-output systems model with strategies, tactics, and external influences influencing the system and the outcomes of interest.

The remainder of this chapter focuses on the explanation and specification of these terms and their application to the drinking water sector. The terminology that will be introduced in this chapter will be applied to the Dutch drinking water system. This serves two purposes. First, this provides a good example of how the terms are used. Second, it positions how the drinking water system is viewed in the remainder of the thesis. The figures will present examples of outcomes of interest (effects), driving forces, and tactics for the Dutch situation in the early 1990's as were found in the case studies that will be described in detail in chapter 7 to 10.

4.2 The system and its boundaries

For this research a system is defined in a very broad sense as 'A collection of entities and the relationships between those entities', in which an entity can be defined as a basic element to which a researcher attributes a collection of characteristics (Kramer and de Smit, 1987). The entities within a system are related. Together they make up the system that shows a certain behavior or performs a certain operation. Entities can be e.g. airplanes, individuals or organizations. This definition implies that a system does not have to be technical or physical of nature. A drinking water company can be seen as a system, but also the drinking water infrastructure itself or the water supply and demand market.

A system is not static. Its characteristics may change under the influence of variables from outside the system, but it may also show autonomous changes, which cannot be explained by factors from outside the system. For instance, consumer preferences can change without a noticeable cause.

A system is distinguished from its environment by choice of a researcher or policy maker on the basis of the phenomena they want to study or take into perspective. We call the separation line between a system and its environment the system boundaries. When studying a system the system boundaries should be chosen fitting to the purpose of the study. This means that the boundaries are set more or less subjectively by a number of criteria that determine what entities should look like to be defined as being part of the system. System boundaries mark those entities that belong to the system for instance with respect to time, geography, or functionality. Note that the concept as adopted here assumes that a decision-maker, planner or designer himself will never be part of the system!

In choosing the boundaries of a system, an analyst faces a trade-off dilemma. If the system is defined too narrowly, this introduces the risk that important factors are overlooked. Conversely, if the boundaries are defined to widely it will be hard to keep an overview of what is important. By defining the system boundaries also the environment is defined, since the relevant system environment can be defined as 'that collection of entities outside the system of which the state is influenced by the system or which influence the state of the system' (Kramer and de Smit, 1987).

In policy analysis practice, those entities that can be influenced directly and indirectly by a decision-maker, and affect the outcomes of interest generally belong to the system. Those entities that cannot be influenced, but exert influence on the system, will belong to the environment. This separation, however, does not unequivocally solve the problem of choosing the system boundaries, since there will always be entities that belong to a 'grey' zone of which it is not obvious whether the entities belong to the system or to its environment.
How the system boundaries are chosen thus largely depends on the problem owner, the problem definition and his outcomes of interest. These outcomes of interest guide the choice of the system boundaries. In addition, appropriate boundaries in time and space need to be determined.

Within a system usually sub-systems can be distinguished. These sub-systems each have a function of their own, but also play a role in the functioning of the larger system that they are a part of (Kramer and de Smit, 1987). Sometimes it is necessary to study a sub-system in more detail to be able to say something about the system as a whole. A sub-system can be considered to be a system itself. This can make it hard to choose a boundary. Focusing on just a sub-system when the focus on a larger system would give better results can be a pitfall. The question that always needs to be answered is: 'On what aspects should one focus to include all relevant functions and influences?'

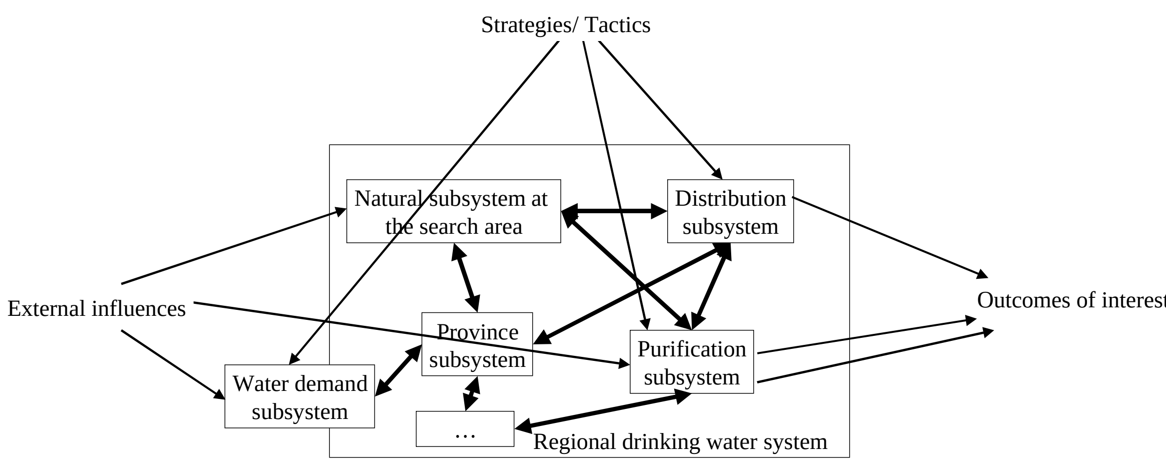

Figure 4.3 The regional drinking water system.

Figure 4.3 shows the regional drinking water system, as an example of how drinking water companies may perceive their span of control of the functioning of the drinking water system. The rather broad perspective is justified to be able to relate different possible angles from which drinking water problems can originate and from which solutions can be found. The system contains next to the natural and the purification and distribution infrastructure subsystems also other sub-systems that directly and indirectly influence the functioning of the drinking water infrastructure. These sub-systems are for instance the province subsystem, which consists of all policy, actions, people, etcetera, from the province in which a drinking water company operates, and the water demand subsystem. There may also be other sub-systems, as is pointed out in figure 4.3 with a blank sub-system.
The regional drinking water system has been chosen with these specific boundaries since the sub-systems that it thus contains can be influenced by the drinking water company. Note that for instance national politics are considered to be outside of the system, even though they can partially be influenced by drinking water companies! Also, water demand has been placed in the boundary zone outside of the system. Water demand is highly determined by factors that cannot be influenced by drinking water companies. It is one of the variables that drinking water companies are uncertain about, while it is a major factor in the decisions that are made. Also, drinking water companies follow water demand rather than try to control it. This would place water demand outside the system. However, drinking water companies have some instruments available to them to influence consumer behavior, such as pricing tactics and the possibility of launching consumer awareness campaigns. This would justify the inclusion of water demand in the system.

To give an idea about the coherence of the system, some possible relationships between subsystems have been indicated. Not all possible relationships have been shown in the figure. The sub-systems and relationships can be described further. I will not do this however in this chapter. Where appropriate they will be specified for each case study.

This choice for system boundaries could have been different. For instance if the focus would be placed on the technological sub-system alone, this would have limited the research space to the physical infrastructure alone. This would not have been a smart choice because in planning processes a lot of other issues do play a role that can not be studied when such a narrow scope is chosen.

In the remainder of this chapter the regional drinking water system is shown as a black-box.

4.3 Unintended external input to the system

Much uncertainty in decision situations comes from outside of the system. A decision-maker has no possibility to directly influence the factors that cause that uncertainty. Therefore it is necessary to name and recognize these uncertainties in order to deal with them in a planning process. In the search for important causes of change it is important to identify *driving forces for change or external influences*. When the causes for change are determined it is possible to determine how important they are, how uncertain they are and which uncertainties are *critical*.

4.3.1 External influences

Every system is influenced by a number of key influences. Many, such as government regulation, come from outside (Schwartz, 1991). Some of them are obvious, others are not. Identifying and assessing these key influences is the starting point of the search for uncertainties. These influences are also called the driving forces that can influence the system and make it change. Examples of these influences are for instance:

- Public health considerations
- Environmental awareness
- Quality of resources
- Water demand rates
- Incidence of veterinarian epidemics
- Transboundary river management plans

More examples can be found in Van der Ploeg and Meijer (1999).

Forgionne (1986) defines external influences as inputs to the system that come from without, which influence the outcomes of interest of the system. External influences are also called external variables, uncontrollable input or environmental variables.

Figure 4.4 shows some examples of external influences that influenced Dutch regional drinking water systems in the 1990's.

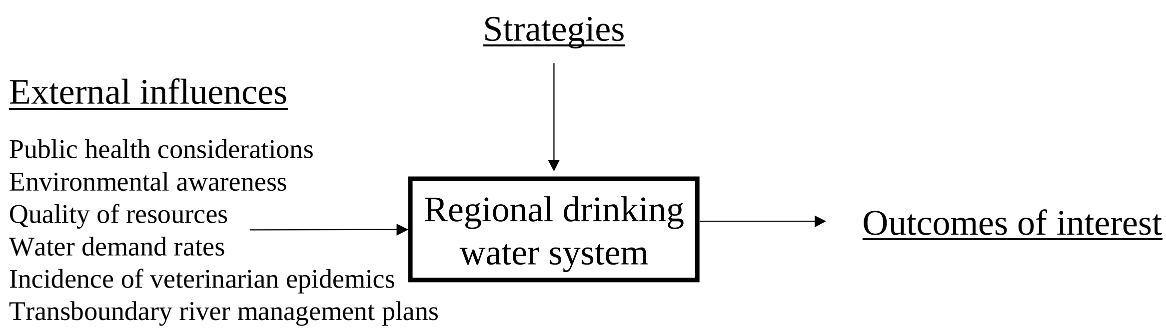

Figure 4.4 Examples of external influences to the system.

4.3.2 Identification of crucial external influences

The identification of those external influences that are important and uncertain for the drinking water sector lays the ground work for devising strategies to handle these uncertainties in a planning process. Seven open interviews with respondents within the Dutch drinking water business, associated with/ working for drinking water companies, research institutions, and consultants (see appendix B for the names of the interviewees), made it possible to establish a list of eight major groups of external influences (Meijer, 2000). These groups are: 1) decisions of other stakeholders, 2) water reserves, 3) the demand for drinking water, 4) organizational mergers and cooperation, 5) regulation, 6) consumer wishes, 7) new technology, and 8) existing waterworks.

Decisions of other stakeholders and their impacts

Decisions by public and private organizations may have consequences for water demand and possibilities to meet this demand. These decisions may affect the characteristics of the drinking water transportation network as well as the demands on volume, pressure, quality and security of the supply. Examples of such decisions made by city planners, project developers, water consumers, and public agencies are: Location and timing of new housing developments; installation of water saving appliances; installation of water re-circulation systems in industry or households; and consumers choices in water use.

Water reserves
The availability of water resources for drinking water preparation is a prime concern for drinking water companies. Water companies cannot be certain about the future quality and availability of their water resources. Groundwater and surface water resources can be polluted with pesticides and other man-made chemical agents which causes certain demands and constraints on infrastructure design. Will pesticides or other man-made chemical agents become even a bigger problem in future than they are today? What technology will aptly purify the source water? Abstraction of ground water is subject to permits from government agencies in the Netherlands. Is a shift to surface water needed in the future? Water companies are not certain if they can extend their current permits to use ground water sources. The quality of surface waters also is affected by decisions in the political arena, for example decisions on sanitation of the sources of diffuse pollution, location of a new airport near a major water storage basin, or permitting of a new pesticide for use in agriculture.

Demand for water
Which users will have to be supplied with water in the future? For a water company it is very important to know the customers and their characteristics in terms of daily and seasonal use patterns but also long-term demands. Industries in large concentrations usually have a very steady, constant demand pattern over the day and during the year. Changes in operation can have a big impact on water use patterns which had been stable over time. Household use has well-known peak demands but use patterns can change with the change of household composition as a neighborhood grows older or becomes rejuvenated through the inflow of young families. The impact of environmental awareness and environmental regulations also changes use patterns. Re-circulation of water in horticulture to reduce pesticide emissions from greenhouses has decreased the drinking water demand in the larger vicinity of Rotterdam. There is also uncertainty about the growth of demand. Total drinking water demand has stabilized in the Netherlands, after years of growth. Will this trend change again and how?

Mergers and cooperatives
Liberalization of the water market in the European Union and commercialization of the water supply industry is leading to mergers and cooperation of water companies. Potential mergers, (un)friendly take-overs or co-operation can have major consequences. Possibilities for water transfers between potential partners may affect the need for expansion of existing facilities, the need for flexibility in a transportation network design, the terms for future contracts for water transfer or the chances for extension of existing contracts. Uncertainty about institutional (re) arrangements thus influences the requirements to the infrastructure system and its design.

Regulation
Privatization of drinking water companies is an uncertainty that has received a lot of attention. Market oriented, cost-effective ways of thinking and use of benchmark studies have consequences for the way in which infrastructures are planned and operated. A recent proposal for revision of the Dutch drinking water law causes uncertainty at different fronts. Diameters of distribution networks used to be dimensioned according to the water demand for fire-fighting purposes. It is not certain how the formulation of public health and emergency standards at national and international level are going to develop in future. How will regulation on this topic develop?

There has been a lot of debate on the pricing structure of drinking water and waste water services. The issue has been raised whether this should be done from a water chain perspective. What effect would such a billing structure have on the drinking water (and waste water) system?

Consumer wishes
Drinking water companies must meet consumers wishes. These wishes can be diverse and change over time. Advertisements and public awareness of environmental issues can play a role in changing consumer behavior. Public health incidents, caused by failure of water supply standards, are known to affect characteristics of water consumption. The further individualization of society may be cause of even higher standards for water security and lower tolerance for health risks. And what does liberalization of the market mean for the possibilities and need for freedom of choice between water suppliers? How will the consumption of bottled water change the need for drinking water supply, and who will supply this bottled water?

New technology
It is difficult to indicate if new technology will become applicable to water companies, what technology this might be and when it will become available. What do future applications of membrane technology look like and how will it change possibilities for decentralization of water purification to neighborhood or even household level? Membrane technology is used more and more to deliver customer-fit solutions. Will other technologies emerge that have a similar impact? Is maximum water saving already achieved for household appliances or is it possible to save more water?

Existing waterworks
Another source of uncertainty can be found in the existing water works. The condition of underground drinking water infrastructure cannot be assessed easily. When should a waterworks part be renewed? To what extent can new technology be used in existing situations?

The list of external influences and possible causes of change of the functioning of drinking water systems summarizes the perceptions of drinking water companies of the uncertainties in their field, as they were articulated in interviews. External influences like the development of water demand rates result, in fact, from other external influences, such as a potential for change in consumer behavior or government regulation. Not all external influences to a system will be critical to decision-making in the design process. Simply listing and grouping uncertainties is a very useful first step in the identification of important external influences, but is in theory not enough to determine the critical external influences that may cause unforeseen changes, and certainly does not give a clue on which strategies may be appropriate to deal with them. In chapter five a general framework is described that does help in focusing in the search for uncertainties.

4.4 Outcomes of interest
All organizations have goals they want to achieve. A goal can be defined as a generalized, non-quantitative policy objective (Walker, 2000). A drinking water company for instance wants to deliver enough drinking water of a good quality. A decision-maker will always want to judge alternative courses of action on their impact to their objectives, to see if actions can be justified. To this end this decision-maker usually (consciously or unconsciously) identifies

outcomes of interest, which can be used as a standard to measure the relevant impacts of changes with respect to the functioning of the system.

In figure 4.5 examples of outcomes of interest for drinking water companies are given.

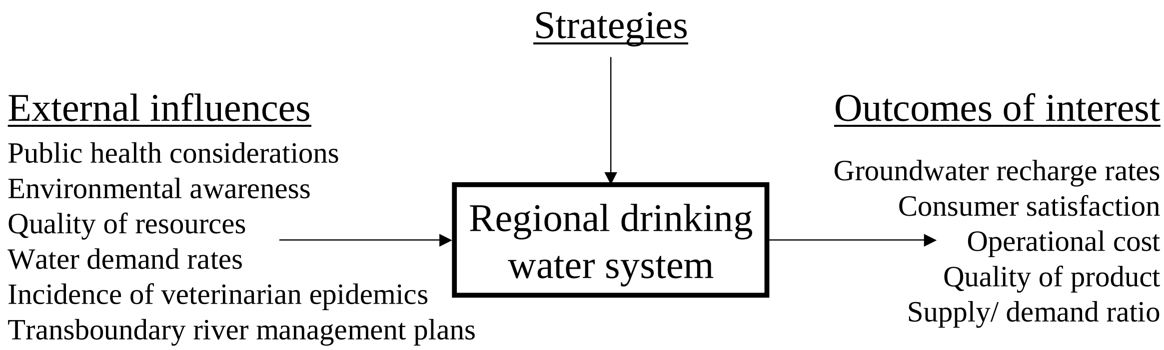

Figure 4.5 Examples of outcomes of interest.

A measure of attainment is necessary for each of the relevant consequences to be able to judge the performance of an alternative. If we want, moreover, to be able to value different alternative tactics or strategies in order to indicate a preference, we need measures of performance, i.e. criteria. The values held by a decision-maker, that is to say, the importance he attributes to the various consequences, determine the criteria (Findeisen and Quade, 1985). For instance when an outcome of interest is to provide a good quality of water, a criterion may be the extent to which a stable good quality of water can be provided. These criteria can also relate to the process of implementation of an alternative. An example of such a process related criterion is: 'the time that will pass until a certain tactic can be implemented should be as low as possible'.

4.5 Strategies

When there is a difference between the desired performance of the system and the actual performance with respect to the outcomes of interest, strategies should be identified that have the potential to tighten this gap. According to Mintzberg (1983) strategy formulation involves the interpretation of the environment and the development of consistent patterns in streams of organizational decisions (strategies) to deal with potential changes. In the process of strategy formulation, tactics may be distinguished (Walker, 1987). Tactics are single things that can be done to meet a goal of a decision-maker. Then, strategies are formed by combining different tactics. Finally the decision-maker will reflect on the alternative strategies that can be implemented and choose the one that seems best. Figure 4.6 shows examples of tactics and strategies that were considered by Dutch drinking water companies in the 1990's. Thus completing the exemplary systems diagram.

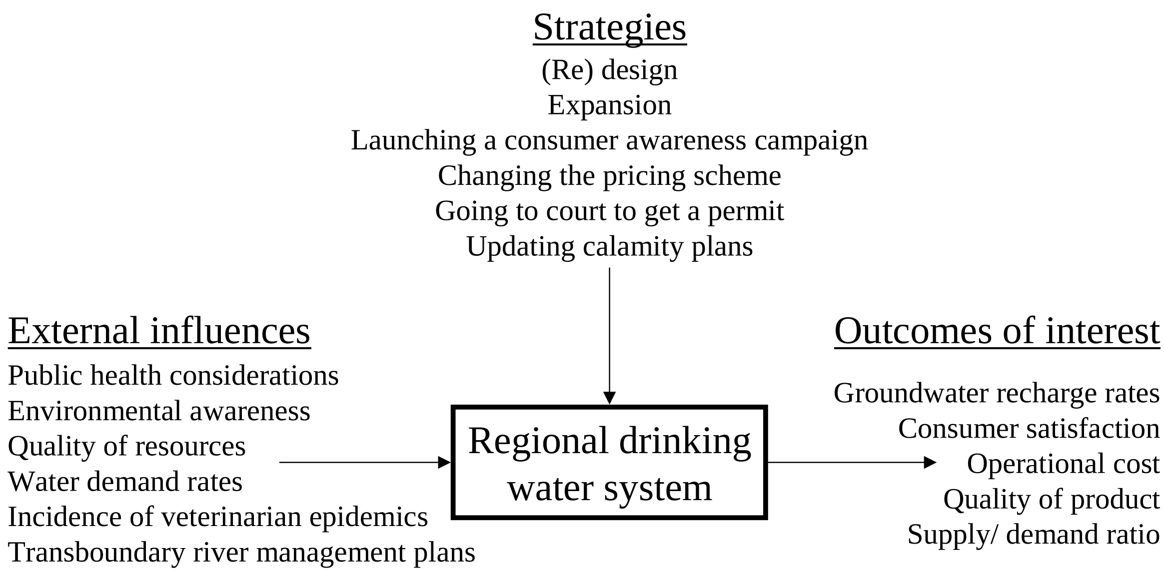

Figure 4.6 Examples of strategies.

4.6 Uncertainties about systems, external influences, tactics, and outcomes of interest

When a systems approach is used to describe a certain part of reality there are uncertainties about each of the elements that make up the system diagram. The following paragraphs present an overview of the most important uncertainties that can be discussed on the basis of a systems diagram.

4.6.1 Uncertainties about the structure of a system

When researchers or policy makers have defined a system by its boundaries a lot may not be certain about that system. Have all relevant entities been included in the system? If this is not the case it may lead to a system in which relevant tactics and strategies have been excluded in the decision-making process. Have all system entities been perceived as they truly are? Was the right knowledge available?

4.6.2 Uncertainties about external influences

Uncertainties about assumptions or about the future properties of external influences that can change the system in such a way that they may affect the decision that is about to be made are critical. The critical uncertainties can be separated from the not so critical by evaluating their effects on the outcomes of interest. Scenario analysis can be used to find out which uncertainties are critical and which are not. By exploring the impact of different values in the external influences in scenario's it can be determined which external influences have what effect in different possible futures. Authors who address scenarios are for instance Schwarz (1988), Schwartz (1991), and Tijink (1999). A short description of how to set up a scenario analysis can be found in Thissen (1999).

4.6.3 Uncertainties about future preferences

Any measure of value is subjective. The same thing may be valued differently by different people (Findeisen and Quade, 1985), and something that today is valued as not important may become important tomorrow. This fact makes decision-making not an easy task of just calculating the best alternative. Even if the decision-maker has a clear image of his or her present preferences, his or her future situation and norms may change in unpredictable ways, leading to other valuations of future outcomes than those made in the present (van Geenhuizen and Thissen, 2002).

4.6.4 Uncertainties about the effect of tactics

Even when careful consideration has been at the foundation of a decision about alternative courses of action, it is still not certain that the chosen strategy has the intended consequences for the outcomes of interest. This uncertainty about the effect of tactics can have three reasons. The effect of the tactic on the system was not assumed well (see uncertainty about the model in chapter 3.3), there have been interfering driving forces or there have been other tactics which changed the system.

4.7 Final remarks

This chapter introduced a framework of terminology based on a systems approach, which connects system performance with external influences outside the control of drinking water companies and alternative tactics and strategies that can be followed to tighten the gap between desired system performance and actual or feared future system performance. The terminology of this framework will be operationalized in chapter 6 and used to describe the case studies in chapters 7 to 10.

Chapter 5. Success factors in dealing with uncertainty: introducing the normative framework

Vision without action is a daydream; action without vision is a nightmare.
Japanese wisdom

This research is aimed at improvement of dealing with long term uncertainties in the drinking water sector. A basis for this can be found in literature on planning, systems and dealing with uncertainty as was described in previous chapters. We will now build on this literature base to identify activities that theoretically can contribute to successfully dealing with uncertainty. In this chapter these activities are named and explained.

5.1 Normative framework

To be able to value whether handling uncertainty was done successfully, a definition of success is necessary. Ideally, the success of handling uncertainty would be defined by the outcome of a decision-making process after implementation of the final decision. However, this would not be a very practical way of measuring the success of handling uncertainty in practice. This has three reasons: 1. Some developments are impossible to foresee on forehand. A project therefore can fail, while the uncertainty analysis has been done properly. 2. Other than uncertain factors may influence the outcome of a project, for instance goals of decision-makers and success definitions may change over time. 3. Evaluation of projects like the ones that were studied would take too long a period to evaluate.

In this thesis, dealing with uncertainty about the future is therefore considered to be successful when there is a preparedness for change. Future changes bring no surprises that could have been anticipated and plans are available to deal with events or patterns that are possible but not certain. This success definition is based on the idea of adaptive policy making as it was described by Dewar (2002). Note that this definition of success does not imply that everything can be foreseen.

The adopted success definition implies that drinking water companies identify all possible future changes and should take conscious actions in face of these changes. This definition of success can be used very well in combination with the rational system diagram approach that was explained in chapter four.

Other criteria related to the success of decision-making processes have been proposed, for instance the extent to which the problem solving process was satisfactory (Twaalfhoven, 1999), whether the process was open, if decision-making took place in a democratic way, if it was efficient or legitimate, etc. We will not focus on these other values, however, as our focus is specifically on the evaluation of success with regard to how uncertainty was dealt with. In every policy analysis and policy process there are trade-offs between each of these values. It is appreciated that in practice always a compromise is made between these values. The fact that just one was chosen was just for research purposes. In chapter twelve this choice is reflected upon.

The normative framework for this thesis is based on the basic idea that given a certain problem, a good and thorough analysis contributes to the choice for wise and well thought through actions, and that wise and well chosen actions contribute to the successful solving of the problem (Twaalfhoven, 1999), see figure 5.1. This causal chain for success should be understood as follows: In the analysis phase of a problem solving process, the problem is specified and possible alternatives to solve the problem are identified and studied on their merits. After this analysis, a well founded choice can be made for one of the alternatives that follows from the analysis. The extent to which the action that is chosen contributes, in the end, to solving the problem determines the ultimate success of the problem solving. Note that a thorough analysis followed by wise actions does not automatically mean that success is guaranteed! They are conditions for success, but no guarantors.

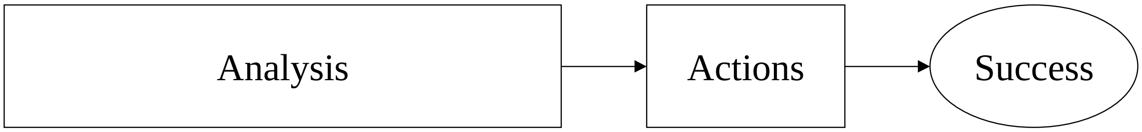

Figure 5.1. Causal chain for successfully solving a problem

This basic idea is applicable to all rational problem solving activities, including planning processes of drinking water infrastructure. Figure 5.2 shows this idea, filled in with a special focus on dealing with uncertainty about the future. In the normative framework that was developed to study the success of dealing with long term uncertainty, the basic idea of the causal chain for successfully solving a problem was used as a starting point. However, success no longer is determined for the overall project, but only for that part that has to do with dealing with uncertainty about the future. The assumption is that when thinking about uncertainty has a place in the analysis and in the actions that are chosen, dealing with that uncertainty will be more successful than when thinking about uncertainty does not play a role in the analysis and the choice for specific actions.
Causality between the analysis, decisions, the implementation of strategies and the outcome of a project is the key assumption in this framework. In chapter 12 some remarks will be made on the fact if this assumption was rightly made.

The remainder of this chapter will address what this ‘uncertainty aware’ analysis should look like and how thinking in terms of uncertainty should be reflected in the decisions that are made, with the ultimate goal of dealing with uncertainty as successfully as possible.

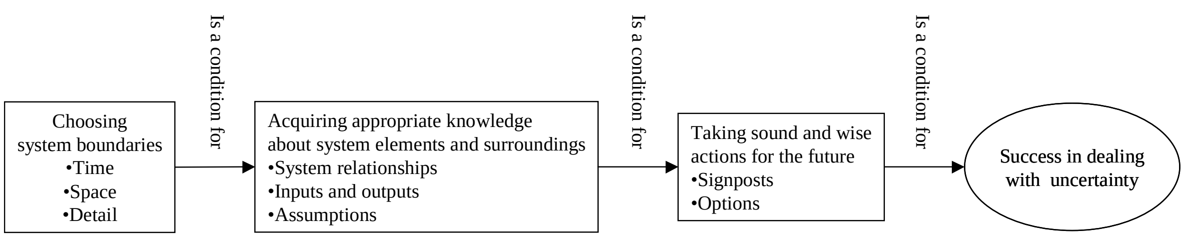

Figure 5.2. Causal chain for successfully dealing with uncertainty

As was mentioned before, in the research outcome success was not chosen as an indicator. As a proxy it was chosen to work with quality indicators for each of the activities in the hypothetical causal framework for successfully dealing with uncertainty, depicted in figure 5.2. The indicators selected show whether a particular activity was performed in such a way that it in theory could contribute to a successful outcome. Two other constraints were formulated to choose the right indicators: 1. They have be operationalizable; 2. They have to be as objective as possible, in such a way that different researchers would come to the same results when the same case is studied.
A lot of possible success indicators are of a subjective nature. See for instance Twaalfhoven (1999) for a extensive list of success indicators. However, the success indicators that are needed for this research have to be as objective as possible to be able to make any judgments

that could also have been made if the case would have been studied by another researcher with the same set of indicators.

Analyzing the system and taking action: anticipating changes
The activity of doing analysis has been split up into two parts, first choosing the system boundaries, and second acquiring knowledge about the system elements and the surroundings that play a role in the drinking water infrastructure planning process. This knowledge concerns the system itself, inputs and outputs to that system, relationships between system elements and external influences, the outcomes of interest that a company has and assumptions about all of these elements that are made during the planning process.

These analysis activities together should, if well done, provide a solid basis for making wise choices with regard to what actions to take while considering uncertainty. For this thesis a choice was made to focus especially on two theoretical ways of taking action to deal with uncertainty; using signposts and using options. Both actions are generally considered as being promising to deal with uncertainly in a rational and systematic way.

A summary of the normative framework, or more specifically of the identified activities, the success indicators used and the theoretic bases used is presented in table 5.1. The specific activities in the analysis and action phase of a planning project and the success indicators that were used to study them in practical situations will be explained further in paragraphs 5.2 and 5.3.

Table 5.1. Summary of the normative framework

	Theoretic base	Activities	Success indicators
Analysis	Systems theory	A1 Determining the system boundaries and relevant relationships	Relevance, consistency
		A2 Acquiring knowledge about system elements and surroundings	
		A21 Inputs and outputs	Richness
		A22 Assumptions	Explicitness
Actions	Uncertainty theory	B1 Using of signposts	Consciousness of the relationship with assumptions, presence of signposts, presence of a contingency plan
		B2 Using of options	Richness, completeness of exploration, presence of options

The success indicators that are chosen will be treated as working propositions. In chapter 12 this research method is reflected upon and it is discussed whether the indicators that were chosen were practical.

5.2 Analyzing the system

The soundness of the analysis will be studied following the lines of the systems approach as presented in chapter 4. The analysis phase was split up in two parts: the first part, in which system boundaries are determined, with respect to time, space, and level of detail, and the second part, in which system elements and their mutual relations are determined.

Accordingly, we distinguish two types of activities in the analysis phase that may contribute to the eventual success of the planning process with respect to dealing with uncertainty:
A1. Choosing system boundaries; and
A2. Acquiring knowledge about system elements and surroundings

The second part was split up into two different activities for practical research purposes, (these activities reflect the basic steps in filling in a system diagram), namely:
Acquiring knowledge about:
A21. System inputs and outputs
A22. Assumptions

Not all parts of these activities will get the same attention in this research. For example, acquiring knowledge about the sensitivity of the system (which normally would be part of A2) or the correctness of data (A21) are not included. As explained in chapter three, the main focus in this research is on structural uncertainties about the future.

In the following paragraphs we explain the selected activities, and develop indicators to use in the empirical research.

5.2.1 Choosing system boundaries

In any planning process choices are made with respect to what issues should be dealt with, what solution space should be considered, on what spatial scale issues should be addressed (for instance regional, local or national) and what time frame will be studied. These choices are made consciously or unconsciously, for instance by setting things aside or by only including a short timeframe in the analysis. Whereas too broad (system) boundaries can lead to disorderliness, too narrow (system) boundaries can lead to missing relevant relations and elements, because related issues are treated as separate ones, future interests are ignored, or relevant solutions are missed.

The system minimally should include those elements that relate tactics to outcomes of interest. This means that the tactics that are considered and the objectives that are aimed for in a project should guide the determination of system boundaries. Complicating in this respect is the fact that a project, in general, will have multiple objectives, for instance to aim at as little public cost as possible, to be self-supporting, or to meet demand.
The system boundary that is chosen can be very appropriate from the perspective of one objective (for instance from the perspective of wanting to deal with uncertainty in a very good way), while it can seem very irrational from other perspectives (for instance political ones). Therefore it is not possible to say that system boundaries were chosen wrongly in general, because some possible objective was not served. This leads to the conclusion that when system boundaries were found to be inappropriate for dealing with uncertainty, it does not automatically mean that they were inappropriate for the process as a whole, since dealing with uncertainty may have not been the most important goal in the process.
In a single actor setting, system boundaries are more straightforward to determine than in a multi-actor setting. The span-of-control of a single actor is more clear, just like the range of possible tactics and system elements that can be influenced. Single actors usually have specific objectives and the system boundaries usually will correspond with that task. Still

different system boundaries can be chosen, for instance because some tactics are deliberately excluded, or because there are multiple objectives to be served with a project.
In multi-actor setting the task of determining good system boundaries is more difficult, since every actor will have his own objectives he wants to achieve. These objectives are often not fully matching and may even conflict. Thus every actor will have its own preference for certain system boundaries.
In a project, system boundaries can change. This is caused by the consideration of new tactics or objectives or a shift in preference of objectives. This does not mean that the former system boundaries were inappropriate, but just that new opportunities were recognized or that objectives have changed.

The choice for a certain boundary for the analysis directly determines the possibilities that are available for dealing with uncertainty about the future, because solution space, scale and time frame have been set. The following example illustrates this. A drinking water company has a water winning capacity problem. In the process of finding solutions, it is decided to look for solutions only within the own service area. This system boundary excludes solutions that can be found with other drinking water companies, such as buying water or starting a shared water winning project.
Setting boundaries has consequences for the quality of the uncertainty analysis. Only aspects will be included in the uncertainty analysis that also have been included in a broader sense within the system boundaries. Too broad system boundaries thus may result in a uncertainty analysis that is also very broad in nature, which can have as a consequence that the results are not concrete enough, too complex to be valuable or simply not reachable within reasonable time and with a fair allocation of resources. Too narrow system boundaries may result in solutions to problems that are overlooked.

It is generally desirable that a good overview is available on all aspects of the system that is planned for, and the relationships with aspects outside the system that can influence how the system functions (see 4.2). However, in complex planning issues there will always be some limitations to what can be known. Even when it would be possible to get a complete overview, this is not an easy task. Planning processes of the scale that is studied in this thesis usually involve many people, and in their communication always some information will be lost. Also several planning processes on different issues may interfere with each other. This increases the danger that sub-systems and external influences are treated as if they are not related, while in fact they are. In addition, ignorance about certain links in a system and with the system environment will add to the fact that there hardly ever will be a complete picture of a system. In this context often the term (de)coupling is used. The term 'coupling' originates from organization theory. I will use the term 'coupling' in accordance with its meaning in that field. In the most broad sense coupling is a term that refers to the extent to which two items or sub-systems or external influences are connected to each other (van Eeten et al., 2000). Policy problems are coupled because at least one of the problems cannot be solved in isolation of the other, because it is inseparably connected to the actions that are taken with respect to the other subject (see for instance: Friend and Hickling, 1987).

When a lot is unclear about a system or if vital system elements are not treated in coherence, this can have major implications for, for example, solutions that are considered. A limited vision of what is important in a project automatically limits the view on what uncertainties are important and also how uncertainty is dealt with. Consider the following example: When a drinking water company is in the middle of a merging process with a neighboring company, but also has a major planning project going on, it is wise of the drinking water company to at least consider the consequences of a merger for the project. If both developments are not put in each others perspective, this may lead to unpleasant surprises. For instance it may happen that the planning project is halted when the merger has become a fact and that investments on the project that were made during the negotiations about the merger turn out not to have been necessary. More reflections on coupling can also be found in Perrow (1984) and Thompson (1967).

The success indicator that would be a logical choice for choosing system boundaries and the most crucial relationships is *relevance*. However, this indicator is very subjective in nature and very hard to assess. Relevance can be indicated by making plausible that the system boundaries that were chosen match with among other things the purpose of the planning process, the planning problem, the period that is planned for and the authority of the organization(s) that needs to take the actions. Therefore as an indirect success indicator *consistency* of boundary choices was chosen. Another success indicator that was chosen for the activity of choosing system boundaries was *consciousness*. Were the system boundaries chosen *explicitly* and preceded with an analysis of what system boundaries are appropriate? Were alternative boundaries considered? These indicators obviously do not indicate the success in dealing with uncertainty but indicate the success of the first step towards a successful planning process in a more general sense. In this thesis the presumption is made that this is a boundary condition for successfully dealing with uncertainty. It was very difficult to formulate an indicator for coupling issues. Therefore it was chosen not to formulate a special indicator but to mention coupling situations if they occurred and discuss the consequences of it in a qualitative way.

5.2.3 Knowledge about inputs and outcomes

As was discussed in chapter 4, system inputs include both external influences that cannot be influenced and deliberate tactics that can be implemented to improve system performance. Knowledge about what external influences and tactics are important and what goals should be achieved as a result of the planning process is of vital importance to be able to assess relevant impacts and make well founded choices. However, on forehand it is very hard to know whether all important external influences and tactics have been considered and whether the relevant ones have been included in the analysis in the right way (see 4.6.2). In addition, it may be possible to determine present preferences or outcomes of interest, but it will be almost impossible to know on forehand if and how they will change in the future (see 4.6.3).

In order to be able to identify proper strategies, critical external influences must be identified in a systematic way and the implications of the different influences must be clarified. One approach to searching for important external influences is running through a list with familiar categories that contain external influences, such as society, economics, politics, technology, and the environment (see the SEPTEmber list that is explained further in chapter 6.5.1). Of course other check lists may function as well. It is not important which list is being used; a list only forms a stepping stone for identifying the crucial external influences that can cause the system to change.

External influences often seem obvious to one person whereas they are unclear for another. For this reason it is better to search for them in teams (Schwartz, 1991). Such group sessions can be supported by methods and techniques that have been developed to stimulate creativity (see for instance Van Gundy, 1988).

Without a complete picture of which inputs are possible and what form and impact they may have it is not possible to make a complete analysis of what uncertainties may be important. Let alone that a good course of action can be determined in the light of uncertainty. The same argument holds for knowledge about present outcomes of interest. If the interests are not known well it cannot be determined in a structural manner which strategy should be followed.

Indicators for quality of the knowledge about inputs and outputs are the *completeness and the richness* of analysis. This indicator indicates the general thoroughness of the analysis and is not specific for uncertainty alone.

5.2.4 Assumptions about a system and its surroundings

In the process of decision-making, assumptions must be made about things that are not known with certainty. Decisions are always influenced by the assumptions decision-makers hold about the world and its future. An assumption is an assertion about some characteristic of the present or the future (Dewar et al., 1993) and can be a fact or a judgement. Note that assumptions can concern characteristics of a system and future developments both within the system and in its surroundings.

Assumptions must be made about all system elements, for instance on how external influences will develop, how the system or sub-systems function and respond to changes, or what future preferences will look like. Awareness about what assumptions are made about certain aspects is of vital importance for the decision on what actions to take. For with a different set of assumptions possibly other decisions would have been made.

For some external elements, assumptions are not that difficult to make. They are either almost certain to change or to stay the same in the course of time. Examples of largely predetermined elements are the growth of a population, which is a phenomenon that can be estimated relatively well, and the number of teenagers at a not too far point of time: children that are born now will be teenagers in a matter of ten years. For other external elements this is not that easy and assumptions need to be made that may turn out not to be or become true.

Any significant plan is based on hundreds of assumptions. Most of them are not explicitly stated and many of these are likely to become true. These type of assumptions are not vulnerable. Others are not critical, in the sense that their becoming untrue will not harm the outcome of a project. Assumptions such as 'The sun will rise tomorrow' or 'People will still buy electricity' or 'Life will go on pretty much as it has for the last few years' are all part of what most of us usually assume about the future. However, among those 'trivial' assumptions can lurk a hidden, implicit assumption that is both vulnerable and critical and that can be dangerous (Dewar, 2002).

Especially for the assumptions of critical importance it is crucial that they have been made explicit. In practice this is not always done, and certainly not in a systematic manner. Dewar in his Assumption-Based Planning method introduces four principles to uncover assumptions. These are: 1) Identifying implicit assumptions in a plan, thus making them explicit; 2) Bringing other minds into the planning process as a double-check, by involving people with diverse perspectives to look at the identified assumptions as a fresh observer, thus enabling them to find hidden or implicit assumptions; 3) Uncovering assumptions by examining the external environment for threats and opportunities; and 4) Revisiting old assumptions (Dewar, 2002).

To be able to say something about the use of assumptions by drinking water companies, the success indicator that was chosen is *explicitness,* which *is* very crucial with respect to assumptions. When assumptions are made explicit, it is easier to see if they become or are true or not and thereby whether action is necessary. Assumptions that stay vague or are made unconsciously cannot serve this purpose. Explicit assumptions also can be a motivation for monitoring efforts that otherwise would not have been undertaken. Explicit assumptions thereby can play a vital role in determining future deviations of what is expected.

5.3 Taking action

When uncertainty is dealt with well this means that the tactics that are considered in one way or another reflect that the systems or outcomes of interest can change. The tactics to a certain extent should be future proof, for instance can be adapted quickly or are robust to change. On the other hand change should be noticed. A signal function should be in place when relevant changes occur (Dewar, 2002). In this paragraph the actions that are necessary in successfully dealing with uncertainty are described.

Without a good analysis it is not possible to make a well founded, balanced judgment on which actions should be taken. Therefore good analysis is assumed to be a condition for good actions. For this thesis two types of actions in light of uncertainty have been studied, that can be part of a overall strategy to deal with a certain problem and that in theory contribute a great deal to the successful dealing with future uncertainty. These are:
B1. The using of signposts; and
B2. The using of options.

Both concepts come from uncertainty literature and in theory fit a proactive and conscious attitude towards dealing with uncertainty (see chapter 3.4). Therefore they are appropriate candidates to be studied in practice with respect their contribution to the successful dealing with uncertainty as was formulated in paragraph 5.1. In fact the use of options and the use of signposts are closely linked, since good monitoring and determining sensible signposts are the only sensible way of knowing when options should be used! However, some options, like robustness that is built in to a system, do not need to be triggered to be active. Therefore the using of signposts and options will be viewed as separate actions.

5.3.1 Signposts

Using signposts is a crucial element in adaptive strategy formulation, which aims at including measures that enable the taking of timely action to prevent bad things from happening or to take advantage of opportunities that present themselves. Thus future changes are planned for and do not come as a surprise. Signposts, for instance, have the potentially great advantage that investments can be postponed, while there is an assurance that it will be recognized in time when the investments actually become necessary. Signposts are not only useful to indicate when action needs to be taken. They also serve as the memory of the company in case of changes of personnel.

The actual *presence* of signposts in a planning process or in a plan resulting from that process was chosen as a success indicator. This indicator was chosen since the mere presence of signposts is an indication of the attitude of planners towards possible future changes. Another indicator that was used is the *connection* that was made *between the identified signposts and critical assumptions.* Were those assumptions that were identified as being critical actually sign posted? In other words, this indicator gives some insight into the *consciousness* of a project team of the relationship between assumptions and signposts. The final indicator that was chosen was the presence of a contingency plan.

5.3.2 Options

In a planning process it is always good to anticipate changes. The option theory is very suitable to point out possible ways of handling uncertainty. In chapter 3.5 four different types of options have been determined.

1. Investing in time
2. Investing in flexibility
3. Investing in robustness
4. Investing in knowledge

Just as for the signposts the actual *presence* of the option philosophy in a planning processes was chosen as an indicator. The presence of tactics with elements in one of the four types of options is an indication of the attitude of planners towards possible future changes just like the presence of signposts is. This indicator indicates whether these options were included in the process deliberately or that their use was a lucky coincidence. Therefore the additional indicators *richness and completeness* of the exploration of options were also used to evaluate the extent to which options are included in analyses and decision-making.

5.4 Final remarks

The normative framework as was presented in this chapter will be operationalized further in chapter 6. In this chapter it will also be explained how the search for practical evidence has been performed. The actual findings of this investigation for four case studies will be presented in chapters 7 to 10 which describe the case studies that were done, and in chapter 11 and 12 in which the overall conclusions will be discussed and evaluated.

Chapter 6. Introduction to the case study research

Wenn de Wind des Wandels weht, bauen die einen Mauern, die andern Windműhlen
German proverb (When the wind of change blows, some will build walls, others windmills).

This chapter provides the outline of how the case studies are performed. It provides information about the objectives of the case studies, what the limitations are of the case study research and how the four cases that were studied were selected. Also a specification is given of each of the elements of the descriptive and normative frameworks that were introduced in chapters 4 and 5. This specification enables the making of specific conclusions on how uncertainty is dealt with in practice and how this may be improved.

6.1 Purpose of the case study research and link with the rest of the research
The main research question that was raised in chapter 1 was the following:

How can the identification and handling of uncertainty in the Dutch drinking water infrastructure planning process be improved?

The empirical part of this work studies and analyses planning processes from the actual drinking water practice and provides insight into how this can be improved when these results are compared with theoretical notions. More specifically the following questions that were raised in chapter 1 will be addressed to arrive at an answer to this main research question:

1. How is uncertainty handled in the current (and past) practice of drinking water infrastructure planning processes?
2. What is the difference between the normative theoretical notions on handling uncertainty and the described practical reality?
3. What parts of the current practice of handling uncertainty can be improved?

To be able to answer the first sub-question, the descriptive framework will be used that was developed in chapter 4. The second sub-question will be addressed with the normative framework from chapter 5. At those points where normative theory and practice differ improvements may be found, either of theory or of practice. Thus question 3 also will be answered. Figure 6.1 presents this case study approach.

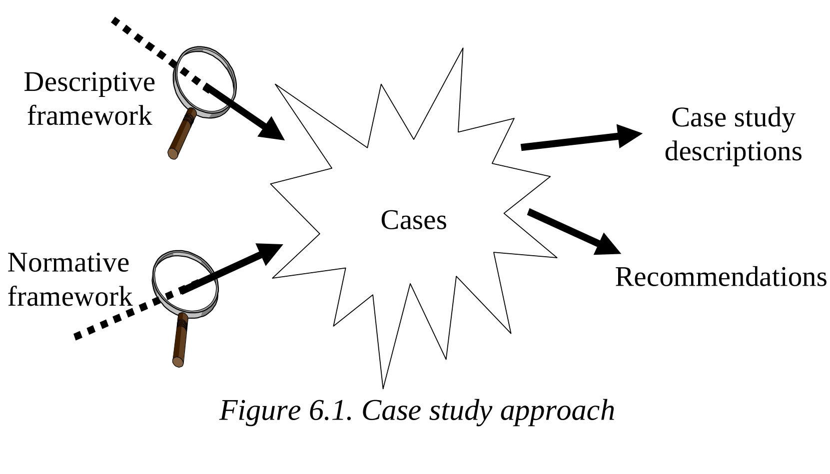

Figure 6.1. Case study approach

A requirement for answering all of the sub-questions is the operationalization of both the descriptive and the normative framework. This operationalization will be presented in section 6.4.

6.2 Using case studies

In this research, case studies are used to learn more about practical ways of analyzing and dealing with uncertainty. It is a proper way to get an in-depth insight in how long term uncertainty is perceived and dealt with in the daily practice of the Dutch drinking water sector. Also, case studies make it possible to study the effect of certain decisions over a long period of time. Alternatives for this approach could have been for instance having many interviews, doing a literature survey or making simulations (Yin, 1994).

The fact that long term uncertainty is studied is the reason why the choice was made to study cases ex-post. Results of decisions over a longer period are known and the research is not hindered by the time a project takes. Especially since drinking water planning projects generally take several years or even decades to be finalized, and results of a planning project will only be noticeable a couple of years after this. A consequence of studying ex-post cases is that the content of a project plays a larger part in the analysis than the process that led to the eventual outcomes of the project, since the process cannot be fully reconstructed in retrospect. This is due to the fact that for instance informal communication during the process cannot be fully retrieved from written sources of evidence or even with interviews. The choice for ex-post cases does, however, allow us to study the (formal) motivation for certain decisions and the consequences of these choices, which are the important issues in this research.

The results of the research were evaluated on the basis of expert consultation. The practical value of the recommendations for future drinking water planning projects were the most important topic of a workshop. Drinking water experts were asked to reflect on this practical value.

6.3 Number and selection of cases

By studying different cases, it will be possible to compare the individual results of each of the case studies. Therefore it may be possible to learn lessons about different ways of planning and the consequences of this for dealing with uncertainty. The choice was made to limit the variety in case studies in order to be able to compare different choices under the same circumstances. The cases needed to be of a relatively complex nature and the decision-making should have taken place in a relatively stable environment. Variations were only made with regard to the drinking water company that was studied and the historical period in which the case study project took place. All cases concern similar but unique one-time investment decisions in regional drinking water infrastructure. Criteria that were used to select case studies were the following:

1. All case studies should concern *Dutch drinking water planning projects*. In this way it is guaranteed that culture, education of people within project teams, the political situation, etc. are comparable for all case studies. The case studies are Dutch for reasons of accessibility of data. The choice was made to study drinking water projects, because this field is relatively stable.
2. The cases should be *regional of orientation*, instead of international, national or local. The regional boundary has been chosen, because this level is both rich and complex enough to be able to make in depth analyses of the events as they happened, but also concrete enough to prevent the analysis to be too general of nature. The local and (inter)national level are less appropriate. Planning on local level mostly concerns operational

deliberations, and on the national level planning is complex, but it does focus on general plans and policies instead of specific drinking water infrastructure planning projects.

3. The cases should concern *large, one-time projects*, that do exceed the scope of daily 'routine' investments. The fact that these projects are large and go beyond routine guarantee that the project organization has a high level of consciousness of what decisions are taken and why they are taken. Therefore there is a larger chance that decisions and deliberations about decisions can be traced ex-post. Besides, these projects are so large that unwise decisions can have large consequences, both financially and for the functioning of the system in the long run.
4. The cases should concern *the same type of projects with regard to content*. The choice was made to study projects concerning the winning of raw water and the purification of raw water to drinking water. This choice for projects on technically comparable issues was made to be able to compare the decisions that were made in the cases. Even within this limitation the projects may differ very much with respect to location, raw water source, the kind of customers that have to be supplied with water, etc. Distribution and transportation projects could also have been studied, but these topics differ too much from winning and purification to make good comparisons.
5. The projects should be *finished recently*. The way people act in face of planning issues depends on state of the art knowledge and those topics that are in fashion in that time. By studying cases from the same period a possible influence of this effect is neutralized. However, the choice for recently finished projects was not only made for reasons of comparability of the results, but also from the practical point of view that this made it easier to find information on the projects and interview people that have been involved in their execution. One exception was made to this principle. One historical case was studied. This has been done to see if the way of dealing with uncertainty is influenced by the spirit of time and to see if learning about dealing with uncertainty has taken place.
6. Finally the cases that were selected were selected on the basis of *availability* and *accessibility* of information.

The cases were identified by sharing the criteria for case studies with professionals from the drinking water sector. The three recent cases that were studied are:

1. The Project Infiltratie Maaskant (PIM), of Waterleidingbedrijf Oost-Brabant (WOB). This project was set up by the drinking water company to plan for an infrastructure that would enable the harvesting and purification of river Maas and Waal water as a source for drinking water instead of groundwater which is the traditional source for drinking water in their region.
2. The Oever-Diepinfiltratie project (OEDI), of Waterleidingbedrijf Midden Nederland (WMN). This project was meant to enable the winning and purification of water from the Amsterdam-Rijn canal instead of groundwater, which is the traditional source for drinking water in their region.
3. The planning of purification facility Jan Lagrand, of PWN, the drinking water company of the main part of Noord-Holland. This project was carried out to realize a large-scale membrane purification facility to expand purification capacity and to be able to deliver less ‘hard’ drinking water.

The more historical case that was studied is:

4) The Lek-duin and the Maas-duin projects of DZH (Duinwaterbedrijf Zuid-Holland). These projects were carried out to transport water from the rivers Lek and Maas to the dunes near the Hague, where it is purified in a natural way through dune infiltration. Decision-making and planning of these projects were studied for the year 1939 to 1965.

6.4 The outline of the case study research

The following paragraphs present the outline of the case study research. The case study research aims at answering the three questions that were formulated in paragraph 6.1. To be able to answer these questions it is necessary to operationalize both frameworks to be usable to analyze cases. This will be done in paragraph 6.4.

The first step in each case study is to uncover the basic story of the studied project and the characteristics of the drinking water company that was responsible for execution of this project. Basic characteristics of the drinking water companies are for instance: who are the stockholders of the company, what does the service area look like, and who are the customers. This knowledge is important for understanding the developments that have taken place in the case. The case will be described chronologically as an introduction and as a basis for further analysis. The rounds concept of Teisman (1992) is adopted to structure and analyse different phases in the decision-making processes. The rounds model of Teisman structures policy processes according to so-called crucial decision-making moments. A round comes to an end when such a crucial decision-making moment has taken place. Within the round itself the discourse stays basically the same. This way of dividing a policy process into rounds can only be done in retrospect, since only then the crucial decision-moments can be pointed out.

The next step is to describe the case using the descriptive framework that was explained in chapter four. A systems description is made for each round that is considered to be crucial to the case. A round is to end when an event or a decision fixes the future solution space or if it marks a turnaround in the policy with respect to the project. The description per round has the following outline:

- Description of the (potential) important external influences that have been acknowledged by the drinking water company and their effects.
- Description of the outcomes of interest that drinking water companies indicate to be important.
- Description of the criteria that have been used to choose between tactics or strategies.
- Description of strategies and tactics that have been proposed by the drinking water company for the concerning round.
- Description of assumptions that have been made about what the system looks like, external influences, their effects with regard to the outcomes of interest and the functionality of tactics.
- Description of the motivation of the final choice for a certain tactic or strategy.
- Listing of sign-posts that were used or considered, monitoring activities and the specified go/no go moments.

This structure provides an orderly account of the motivations for decisions that were taken in the case. The advantage of working with decisions or events that mark the ending of a round is that these represent moments in time of which usually good documentation is available. Because the discourse within the round is relatively stable, it is possible to describe the arguments that are brought forward within the round using the reports that are made at the end of that round.
The identification of each of the aspects of a system diagram, i.e. external influences, tactics, outcomes of interest, etc., lays the ground work for the normative analysis, which is the following step in the case study. The descriptive results from the previous steps are confronted with the normative framework that was presented in chapter 5. In chapter 6.5.2 it is elaborated how this is operationalized.

When all previous steps have been taken for all individual cases, a comparison will be made of the four case study results.

6.5 Specification

A further specification of the descriptive and normative framework is necessary to be able to make a comparable analysis of each of the four selected cases.

6.5.1 Specification of the descriptive framework

The terms external influences, outcomes of interest, strategies and tactics were explained in chapter 4. However, they need to be specified to be able to search for them in a structural way in the cases. This specification will be formulated in the following few paragraphs.

External influences

In chapter 4.3.2. many external influences were listed as they were mentioned in interviews. Further structuring of external influences is necessary to be able to classify the external influences that are found in the case studies. The following list of external influences, which also was mentioned shortly in chapter 5, is often cited (e.g. by Schwartz (1991), and van der Heijden, (1996)): Societal developments, Economic developments, Political developments, Technological developments, and Environmental developments. The list is also called the September list. Each of the identified external influences will be characterized according to this list.

- Societal developments. External influences of this type have to do with the behavior and wishes of people, organizations, and companies. Examples are the development of the demand for drinking water by farmers, or the rise of the demand for 'custom made water' by industries.
- Economic developments. Economical external influences concern developments in the economical market and finance. Examples are the rise of competition in the water market and the strive towards up-scaling of drinking water companies. This force manifests itself for instance in the form of mergers and cooperation agreements.
- Political developments. Political external influences concern political decisions, policies and regulation directly of indirectly related to the operations of drinking water companies. An example is the change of the river law.
- Technological developments. Technological external influences have to do with technological breakthroughs and the development of scientific knowledge with respect to drinking water technology. An example is the development of membrane technology.
- Ecological developments. External influences with respect to ecology and nature concern changes or events from the physical environment of the system under consideration. Examples are climate change, incidence of veterinarian epidemics or the presence of pesticides in groundwater.

Some influences may be classified in more than one of these categories. If this is the case, these external influences will classified as being of more than one type. External influences that influence a drinking water company indirectly, for instance by influencing drinking water customers to show a certain behavior, will be classified according to the direct influence that can influence the drinking water system. For instance if a farmer makes economically driven decisions that influence his water demand, this will be classified as being a societal development, because this force does not originate from the economical environment of the drinking water company system as such. Besides, for this example the financial stimulus to demand less water can be caused by political decisions as well. The orderliness of the analysis will be lost if the causes and effects of this force would be classified in all three categories.

Outcomes of interest and criteria
The outcomes of interest for drinking water companies have been categorized with the use of two sources: 1) The policy plan drinking and industry water supply (Ministerie of VROM, 1993), and 2) the VEWIN benchmark (VEWIN, 1999). In the policy plan the basic ideas for the policy on drinking water and industry water have been identified on a national scale. The most important goals that drinking water companies have to comply to with regard to the supply of drinking water now and in the future are:

- Guaranteeing drinking water quality
- Guaranteeing the continuous delivery of drinking water
- Every person should at all time have sufficient water of a sufficient quality at his/her disposal
- The carrying capacity of the environment should not be compromised
- Developments should only take place at socially acceptable cost

The VEWIN benchmark study (VEWIN, 1999), which compared most Dutch drinking water companies on their performance also recognizes the goals that were stated above and adds one:

- Having a good service level and a high customer satisfaction

All these goals have been translated for the purpose of this thesis to outcomes of interest on which a drinking water company should score well. All of these outcomes of interest should be able to be quantified to some extent, since this makes it possible to track changes in scores on these outcomes of interest in the course of time. The following categories of outcomes of interest have thus been identified.

- Quality of the final product
- Continuity of delivery of the final product on the short term (security of delivery, prevention of failures)
- Continuity of delivery of the final product on the long run (prevention of shortages)
- The extent to which the environment is influenced/ harmed (think about: occupation of space, stench, noise, aridification, use of chemicals). In a lot of final reports environmental outcomes of interest are represented in just one parameter, which is often not specified further. This makes it difficult to analyze these parameters in greater detail and evaluate the decision.
- Cost (for customers: tariffs; for drinking water companies: among others operational, physical infrastructure, and depreciation cost)
- Extent of customer satisfaction

The norms based on the formerly presented list of outcomes of interest often are complemented with norms or constraints that reflect extra demands. These norms of constraints like these are only relevant up to the realization of an alternative. For example:

- The use of proven technology, to make sure that the final solution functions as expected
- Realization time of an alternative
- Compliance with new or existing regulations or insights

In the analysis an identification will be made to what extent the formerly stated six categories of outcomes of interest have played a role in the decision-making process. Also it is identified which other criteria have been used in the decision-making process and which of these were the most important motivation to the final decision.

Tactics

We will divide tactics in three categories. In the case studies it will be investigated which category of tactics is mostly used, why this is so and whether there are opportunities in using the other categories more often. The three categories are:

1. Tactics aimed at changing the technical infrastructure. These tactics physically change how the system operates (for instance by adding an extra pumping station to the infrastructure or by using different technology that reduces the sodium content in the drinking water).
2. Tactics aimed at those elements of the system that are not within the technical system. These tactics are aimed at the influences on how the technical system functions, and are meant to strengthen or weaken these influences (Think for instance about trying to influence the demand of drinking water by drinking water saving campaign).
3. Tactics that aim at the effects of the technical system performance. These tactics aim at compensation of the negative output of the technical system or at enlargement of positive output (for instance buying insurance for if the technical system fails).

6.5.2 Specification of the normative framework

The six main activities that have been identified within the normative framework, namely the choosing of system boundaries, acquiring knowledge about the system, subsystems and relationships, acquiring knowledge about system inputs and outputs, identifying assumptions, using signposts, and using options, will have to be specified further to be able to get comparable case study results. In this paragraph all these activities will be specified.

System and relationships: relevance, consistency

To know whether system boundaries were consciously chosen, explicit statements of what system boundaries were adopted were sought for. The consistency of system boundary choices was determined by comparing system descriptions, the identification of tactics and external influences and determining if these all concern the same scale. If this was not the case, the choice for system boundaries cannot be considered to be consistent.
The system boundaries will be considered to be relevant when the problem owner has influence on the tactics that are determined.

In a single actor situation almost always the system boundaries chosen will be relevant, because there will be a match between the objectives of the actor and the alternative tactics this actor will consider. All studied cases concerned more or less single actor situations in the sense that objectives and decision space were fully determined by the drinking water company itself. Other actors did not so much co-decide, but only posed boundary conditions to the choices that were made. Therefore the relevance of the system boundaries in these case studies does not need further studying. System boundaries become interesting in the case studies when they shift. How does this shift relate to dealing with uncertainty?

In the search for possible de-coupling phenomena, the following facts are listed for each case study:

1. Listing of external influences that are recognized by the drinking water company but of which is claimed that not enough is known to incorporate it in decision-making
2. Listing of external influences that are not included in decision-making for other reasons
3. The type of external influences that are not included in decision

De-coupling phenomena will be indicated when seen in the cases. There is, however, not a clear recipe on how to recognize them or to be sure that all of them have been recognized. The previous list will not directly point at de-coupling phenomena, but it can give a clue to where they might have played a role. Recognizing de-coupling phenomena is the first step in making recommendations about how to try to prevent them in the future.

Inputs and outputs: richness
To be able to know if the analysis of system inputs and outputs by drinking water companies in the studied case was complete and of good quality, and where improvements may be found, the following facts are listed:
1. The type of external influences that are recognized by the drinking water companies (see 6.6.1)
2. The type of outcomes of interest/ criteria that is recognized by the drinking water company (see 6.6.1)
3. The type of tactics that is used by drinking water companies

With these lists it then becomes possible to make statements about whether possible important types of external influences, tactics or outcomes of interest have been overlooked or have not been mentioned and about to what extent concerns about the future play a role in planning.

Assumptions: explicitness
To know more about assumptions that are made in practice and how much attention they are given, the following questions need to be answered:
Are assumptions made explicit in a systematic way?
Which assumptions were made explicit?
Of which type were these assumptions?
Were these assumptions questioned?
Which assumptions turned out to be true, and which not?
Of which type were these true or untrue assumptions?

The answers to these questions will be in the form of lists. Assumptions will be identified with the descriptive framework as a guideline. Do they concern an external variable, a characteristic of the system, an outcome of interest, etc.? The type of assumption then will be specified according to the further characterization of these elements in the descriptive framework, for instance about what type of external variable is this assumption made according to the September list (see 6.4.1)? The result of this exercise will be an impression about what the most difficult assumptions are in planning processes, and if these assumptions were made explicit beforehand.

In chapter 5.2.4 theoretical methods to uncover assumptions were mentioned. A quick scan of the empirical data showed none of these activities could be found. To avoid the repeating of this statement in all four case studies it is addressed further in chapter 12. To investigate whether one of the suggestions of Dewar (2002) to look for assumptions in texts could be used for Dutch texts as well this was tried for one of the case studies. It turned out to work pretty well, with a view problems caused by the difference between Dutch and English (see appendix A).

Using signposts
To evaluate the use of signposts the following questions ideally will be addressed:
Are signposts identified explicitly in combination with the strategy that was decided upon?

To what type of assumption are these signposts directed?

A signpost will be recognized as such when a monitoring scheme, with some threshold or event attached to it, is identified as a part of a plan for action or a strategy. Monitoring activities with or without project-specific events or thresholds that are not initialized as a part of the studied project, but are more general with respect to company policy, will be not considered to be signposts that concern the specific decision that was studied. The goal of this exercise is to know to what extent signposts are used in practice. And if so, with respect to which assumptions? If not, why not?

The research, however, revealed no signposts in any of the cases. In the case study chapters, they are not mentioned. Chapters 11 and 12 reflect on this matter.

Using options
Every tactic can contain one or more option elements, as was explained in chapter 5. For instance, a new purification plant can be designed to use two sources of raw water. In the case studies all option elements that are recognized are listed according to the following categories that were already explained in chapter 5:

1. Investing in time
2. Investing in flexibility
3. Investing in robustness
4. Investing in knowledge

For each option an indication is given why it was used. This is done to answer the following questions: Which type of options are used most? For which reasons are these options used? Are there potential beneficial options that are not used (frequently)?

6.6 Data collection
To get a reliable image of the case studies and the results of the case study analyses, different sources of information have been used, namely written official documentation, open interviews with people who were involved in the projects that were studied (see appendix B for the interviewees), comments of people involved in the projects on the preliminary case study reports, and the results from an expert opinion workshop in which the results of the case study analyses were presented.

The case study analyses are based as far as possible on official written documentation on the projects, like for instance project plans, annual reports of drinking water companies, minutes of board meetings, etc. This is the easiest way to follow the (official) line of argumentation that lays behind choices that are made.

Written information is a more 'objective' source of information than for instance information from interviews. Nevertheless, interviews were used to gain insight into the gaps in the written information and to get extra background information on the projects and the rounds that have been analyzed. This is the only way to get a feeling for the more informal motivation of decisions and the process of decision-making, which most of the time is not documented directly.

The case descriptions that were based on the written information and on interviews were read by the interviewees from the drinking water companies to see if the representation is correct.

This activity often led to additional information about the cases. If necessary this step was repeated several times.

The final source of information were the results from the expert opinion workshop. The recommendations that followed from the analysis of the four cases were presented to experts from drinking water practice to evaluate the results. The input that the experts gave was used to improve the recommendations. For the workshop, the research findings were used as input to a case on which the workshop participants had to answer multiple choice questions. They were also used to formulate propositions for with the participants had to agree or disagree and to explain why this was so. Finally the participants were asked to make a SWOT (strengths, weaknesses, opportunities, and threats) analysis on the way that drinking water companies deal with uncertainty. The results of each exercise were used as triggers for the discussion on how uncertainty is dealt with in practice and what could be done to improve this. Appendix B shows the list of participants. The results of the workshop have been used in chapter 12.

6.7 Boundaries of the case study research

In the case study plan, some research boundaries implicitly have been set. The description of external influences will be limited to those that were identified by the drinking water companies or that turned out to be critical. This is possible, because only ex-post case studies are analyzed. In case of a real-time case study, an analyst has to decide for each external variable if it may be critical. Naturally, in each case study some external influences will be identified by the drinking water companies that turned out not to have a critical influence on the outcome of a project. These will be named explicitly.
Finally, no judgments will be made about the correctness of decisions that were made as they were made and when they were made. These kind of statements cannot be made with the case study outline that was proposed. It is not suitable for that purpose.

6.8 Outline of the case study reports

The case study approach that was presented in this chapter was used to analyze four case studies. The reports of these case studies can be found in chapters 7 to 10. Each of these chapters has the following outline:

1. Description of the context of the case
2. Chronological description of the case
3. Descriptive analysis
4. Normative analysis

The comparative analysis of the case studies will be presented in chapter 11, followed by practical recommendations to drinking water companies in chapter 12.

Chapter 7. Case 1. PIM

Modest doubt is called the beacon of the wise.
William Shakespeare, Troilus and Cressida, II, ii, 56.

This case study concerns the decisions that were made by Waterleidingmaatschappij Oost-Brabant (WOB) with respect to their PIM project (Project Infiltratie Maaskant). This project was started to plan for new water harvesting and purification works that would enable the use of water from the rivers Maas and Waal as a source for drinking water instead of groundwater.

Figure 7.1 Service area of WOB until 2002 (white)

WOB delivers water in the eastern part of Noord-Brabant (see figure 7.1). WOB traditionally is a self-winning groundwater drinking water company even though two major rivers run at the border of their service area, the river Maas and the river Waal. The area that WOB serves has much agriculture. About one quarter of the total drinking water produced is sold to middle large users, which are mainly farmers. In the past the percentage of water that was sold to farmers was higher, but nowadays many farmers harvest their own groundwater.
January the first of 2002 WOB merged with neighbor WNWB (NV Waterleiding Maatschappij Noord-West Brabant) to Brabant Water N.V. This new drinking water company serves the whole of Noord-Brabant except for Tilburg, which has its own drinking water company TWM (Tilburgse Waterleidingmaatschappij). However, since the events that are described in this case study are from before that date, the drinking water company will be addressed as WOB. However, discussions about the merger already took place when the PIM project was developed. Therefore it is important to know that WNWB is one of the three shareholders in water winning company NV Waterwinningbedrijf Brabantse Biesbosch (WBB). This company harvests drinking water from a large surface water reserve in the Biesbosch. Some core figures about WOB can be found in table 7.1.

Table 7.1 Facts about Waterleidingmaatschappij Oost-Brabant (before the merger)

NV Waterleidingmaatschappij Oost-Brabant (WOB)		
Service area	Eastern part of North-Brabant. Large cities: Eindhoven and 's-Hertogenbosch (see figure 7.1)	
Neighboring companies (situation until 2002)	WNWB and TWM (west), WML (Waterleiding Maatschappij Limburg, east), WG (Waterbedrijf Gelderland, now Vitens) (north), and two Belgian companies PIDPA(Provinciale en Intercommunale Drinkwatermaatschappij der Provincie Antwerpen and VMW (Vlaamse Maatschappij voor Watervoorziening) (south).	
Bulk contracts	Purchase from WML[1]	
Water source	Groundwater	
Total amount of water delivered [1]	107 million m^3 (1999)	
Percentage of total m^3 delivered to types of customers(1999) [1]	Small users	56 %
	Middle large users	24 %
	Large users	14 %
	Own use and delivery of different water	6 %
# Connections [1]	580 thousand (1999)	
Shareholders	Province North-Brabant and the municipalities in the service area, the Province owns the majority of the shares	
1. WOB, 2000a		

7.1 Historical description 1972-2000

In 1972 the Dutch national government presented the first national drinking water scheme (Ministerie van Volksgezondheid en Milieuhygiëne, 1972). In this document, among other things, plans were made for the possibility that the groundwater reserves would be used up to the full extent. For the eastern part of Noord-Brabant several options to use surface water instead of groundwater for the preparation of drinking water were identified. One of the options is the realization of a basin and a infiltration purification between the river Maas and the river Waal. This project should be able to deliver 150 million m^3 water per year.

This plan was just an exploration for the future to anticipate the possibility that the drinking water demand would rise significantly. Some years later, however, aridification became an important political and social issue. In the second national drinking water scheme (Ministerie van Volksgezondheid en Milieuhygiëne et al., 1981)) and in other national plans, such as the Nature Policy Plan, and the third Water Management Act (1990) the search areas for surface water winning were selected and regulation on this subject was detailed further. This put more pressure on provinces and drinking water companies to explore alternative options for using ground water for drinking water preparation.

The national policy was translated into more concrete goals by the province of Noord-Brabant in their first water management plan- 'Werken aan Water' (1991). The following of these goals were important for WOB:

- Aridification should be halted, in accordance with the third water management act. The extension and intensity of aridification may not increase with 1989 as a reference year. This goal was translated into a stand-still policy for the total amount of groundwater extraction in the area with 1987 as a reference year.

- Further growth of drinking water demand after the year 2000 should be met with surface water.
- Groundwater should be used as much as possible for high quality purposes, i.e. for drinking water preparation and other purposes that need water of a high quality that are related to public health. Extension of the use of ground water for these purposes can only be realized when other uses have been reduced, for instance the use as cooling water.
- In middle and eastern Noord-Brabant a surface water project should be realized with a minimum capacity of 10 million m^3 water per year.

The drinking water demand in the eastern part of Noord-Brabant showed an increase until 1989. In those days, the future gross drinking water demand was expected to grow above 142 million m^3 per year, which then was the maximum amount of production capacity.

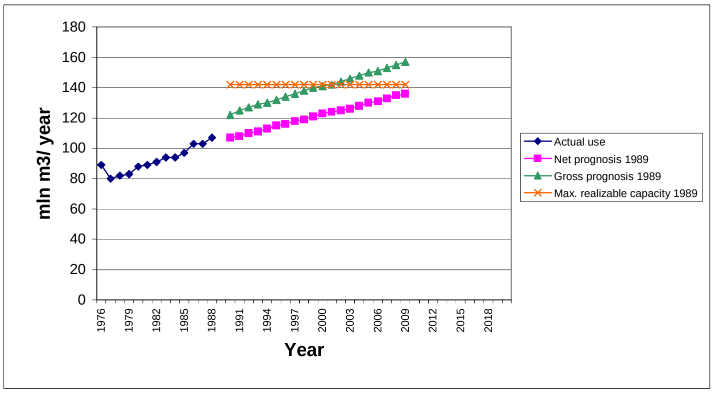

Figure 7.2 Actual drinking water use in eastern Brabant from 1976 until 1988 and prognoses from 1990 until 2010[1] *(WOB, 2000b)*

For WOB the Provicial water management plan had as a consequence that their permit to extract groundwater would be decreased with 10 million m^3 from 108,7 million m^3 per year in 2000 to 98,7 million m^3 (WOB et al., 1995). WOB was not pleased with that and in their opinion it was not a good idea to realize a large surface water project, because groundwater is a much better source for drinking water and there is doubt about the assumption that ground water extracting for drinking water is a large factor in aridification. This can be concluded from the interviews that were held and the notes of the RvC meeting of 7 may 1990 and 8 October 1990 (WOB, 1990).

Nevertheless in 1989, anticipating the guidelines of the provincial plan of 1991, they started an investigation on which options were the best to be able to supply the estimated future demand using other sources than ground water. Different ways of purification were researched, such as depth infiltration, winning of river bank water and open infiltration of surface water. Also the possibility of buying water from neighboring drinking water companies was researched, such as water from the Biesbosch, from WML from their new to realize surface water project or from Duinwaterbedrijf Zuid-Holland (DZH).

[1] Drinking water prognoses are calculated both net and gross. The net prognosis presents the expected water demand. The gross prognoses adds 15% to reckon with the effects of unexpected situations, like an extreme dry year, uncertainties in the prognosis itself, unexpected demand by existing customers or the arrival of new (industrial) customers.

Of all these options, open infiltration of surface water scores best with regard to environmental benefits, security of delivery, the quality of the end product and last but not least the cost.

In 1990, WOB decided to start with the realization of PIM, feeling they had no other choice. The plan of PIM was based on the following technological basics: water would be won from a basin with an inlet from the river Maas and potentially also from the river Waal. This water would be pre-purified and then infiltrated through surface infiltration into the ground. After some time this water would be pumped up again and undergo a final purification before it could be used as drinking water. The estimations of what PIM would cost were ƒ417 million (+/-€190 million).

Procedures were started to get all necessary permits, designs were made for all works in the planning area and ground was purchased. Even the actual work in the area started, mainly with respect to the basin.

Halfway the nineties water demand appeared to be less than previously was expected (see figure 7.3). It stabilized and even dropped a little. The explaining variables prove to be the success of water saving actions and the so called ' water flight' of farmers. The water flight was initialized in 1995 by increased taxes on groundwater use. The drinking water company was forced to increase the drinking water price with ƒ0.34 per m^3 (+/- € 0.15). For many farmers it became interesting to pump up their own groundwater, which is free of registration (and uncharged) for pumps that pump up less than $10m^3$ per hour, and in total less than $5000m^3$ per quarter of a year (Dutch Groundwater Law). And for installations that are mainly used for irrigation purposes that pump up less than $60m^3$ per hour.

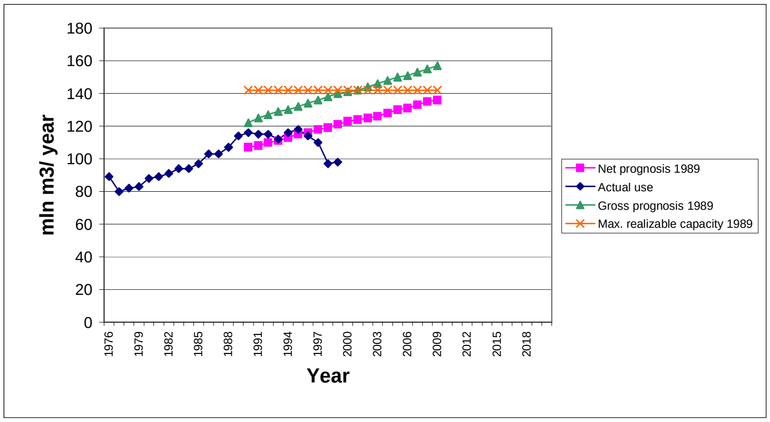

*Figure 7.3 Actual drinking water use in eastern Brabant from 1976 until 1999 and prognoses from 1990 until 2010 (*WOB, 2000b)

Initially it was not certain whether this decrease would sustain. Thus WOB continued the preparations of PIM.

In 1993 a new national policy plan for drinking and industry water was published (VROM, 1993). The plan argued that groundwater was still the best source for drinking water to be able to make a reliable end product. It also said that the use of groundwater should not lead to destruction of the environment. For WOB concretely this meant that they were strengthened in their argument that groundwater was the best source and that it should be used for drinking water if it did not harm the environment. A surface water project therefore is unwanted when groundwater resources are used in a sustainable way.

Some other developments took place that made WOB wonder if PIM was such a good idea. When PIM was started the choice was made to use the open infiltration technique since at that time this was the best available and proven technology. However, soon after other promising techniques became available and proven, such as membrane and depth infiltration. The technology of PIM thereby became outdated.
Also, getting all necessary permits proved to be more difficult than thought. In the light of the national policy ' Space for the River', the last needed large permit was not granted. The basin would claim to much space in the river bed. To get this permit, law suits would be necessary.

In 1998 a new director was appointed, the now deceased mister Jellema. In anticipation of his appointment a couple of decisions were postponed, also about the continuation of PIM. The new director proved to have a different management strategy than his predecessor and had a different vision on how WOB should prepare itself for the future. From this new perspective mergers were discussed with neighboring drinking water companies and a large and expensive project like PIM was put in a different perspective. It appeared that WOB didn't need the project any longer to meet the stand-still policy of the province and still be able to deliver a sufficient amount of drinking water.

In consequence, in the summer of 2000 WOB announced that PIM would not be continued in the same form as was initially intended. At that moment ƒ85.2 million (€38,7 million) had been spent on the project. WOB hopes that this money was not spent in vain. The project is hoped to be carried through on a smaller scale and with the use of up-to-date technology.

The box below shows an overview of the events as they occurred and were described before:

Historical overview

Period 1972- 1991	*Continuing growth of drinking water demand, translation of national goals with regard to aridification into concrete actions on a provincial scale*
1972	National drinking water scheme: limits to groundwater extraction, first mentioning of PIM
1991	Provincial Water Management Plan: National goals with respect to aridification are translated into actions, standstill of groundwater extraction capacity with reference year 1987, no extra groundwater extraction permits are granted
Period 1990- 2000	*Detailing of PIM*
Period 1990- present	*Drinking water demand comes to a standstill, new technology for drinking water preparation becomes proven*
1990	WOB decides to start the preparation of PIM, pressured by the Province
1993	National Policy Plan for drinking water and industry water supply: groundwater is the best source for drinking water if used in a sustainable way
1995	Increased national taxes on groundwater use, resulting in 'water flight'
2000	Halting of PIM

7.2 Selection of important rounds

Two rounds were selected to be studied further. First the round that led to the decision in 1990 to implement PIM will be studied. The decision that action was needed had already been taken at that point! The second round that will be analyzed is the round that led to the decision to halt the project in 2000.

7.3 Round 1: Selection of tactics, 1989-1990

In 1989 the first study about a large scale surface water project was carried out. In 1990 different alternatives to get purified surface water were compared to each other and to the alternative to use more groundwater. This was the last moment that the decision could be taken to invest in a new to be built surface water winning station or to connect to water from neighboring drinking water companies. The reason for this was that the ground water reserves were expected to be used up in ten years time, and the estimated realization time of a new facility was a similar period. This decision was analyzed further based on a summary about this decision in the Environmental Impact Assessment of PIM (WOB et al., 1995). The summarizing system diagram can be found in figure 7.4.

7.3.1 External influences and outcomes of interest

The analysis of the documentation on the decision to implement PIM resulted in the identification of the following external influences that were explicitly taken into account in the analysis and decision-making process and their (potential) effects:

1. Development of the demand for drinking water. The demand for drinking water was expected to rise. That would imply that there would be a shortage of water in the year 2000 when all available water winning capacity would be used.
2. Aridification policy. National government demanded that aridification should be halted and that a stand-still policy on the pumping up of groundwater should be aimed at.
3. The realization of the fourth Biesbosch basin. It was uncertain whether this basin would be realized. If it would not, the capacity of the three existing basins would not be enough to supply WOB as well next to the traditional users of the basins. WOB therefore assumed that the tactic to buy water from NV Waterwinningbedrijf Brabantse Biesbosch was only possible if the fourth basin would be realized.
4. Development of technology. At that time some promising technologies were being developed for purification of surface water, namely membrane technology and depth infiltration. These technologies were in the center of attention, but it was not certain when these technologies would be proven.

7.3.2 Strategies and tactics and outcomes of interest

When WOB decided that extra winning and purification capacity was needed a choice needed to be made about how this extra capacity was going to be realized. The following tactics were taken into consideration. Logically all these tactics affect the technological system:

1. Winning of surface water near Lith and purification with the use of open infiltration technology. With this process a good product could be guaranteed. The realization time of the winning and purification facilities would be short and the technology was proven. This tactic, however, would consume a lot of space.
2. Winning of surface water near Lith and purification with the use of depth infiltration. With this process a good product could be guaranteed. The realization time, however, would be uncertain and the technology was not proven yet.
3. Winning of surface water near Lith and purification with the use of river bank infiltration. The quality of the product is difficult to control and security of delivery could not be

guaranteed. A good point of this technology is that the ground water drop would be limited.

4. Using more ground water. This tactic was preferred but not studied further, since a standstill of groundwater use was issued for reasons of aridification and the natural limit on the amount of water that can be won.
5. Buying pre-purified water from DZH (Duinwaterbedrijf Zuid-Holland); The cost of this tactic was considered to be high. The realization time was uncertain. Also this alternative does not score well on the factors 'environment' and 'protection' (both concepts are not explained further in the EIA).
6. Buying pre-purified water from the Heel basin of WML. The capacity of this basin, however, was not considered to be large enough to supply both WOB and WML.
7. Buying of pre-purified water from the Biesbosch from WBB. The cost of this option was considered to be high and the capacity of the Biesbosch basins was not thought to be large enough unless a fourth basin would be realized.
8. Realizing a new surface water winning basin near Beers. This option was considered to be difficult to realize in a technical sense. Also this alternative did not score well on realization time and environmental aspects.

7.3.3 Choice

WOB preferred option four, using more ground water. But because of political pressure to use surface water, the first tactic, namely the winning of surface water near Lith and purification with the use of open infiltration technology, was in the end considered to be the best option. Also more research was issued on depth infiltration technology.

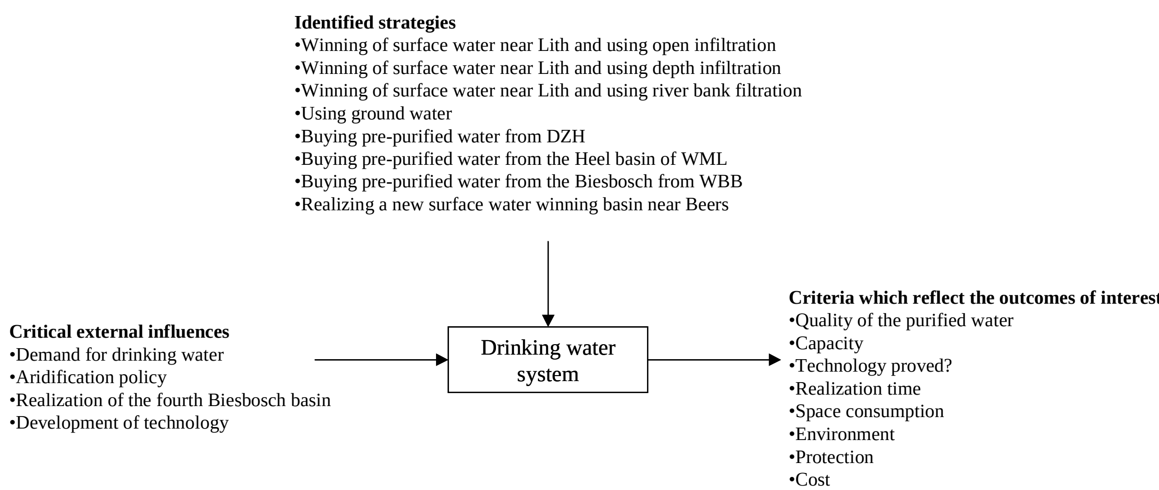

Figure 7.4 System diagram of round 1, 1990

7.4 Round 2 Halting of PIM, 1993-2000

This round concerns the events and considerations that led to the halting of PIM in 2000. This round starts in 1993 with the publishing of the national policy plan for drinking and industry water, which underscored the use of groundwater as the best source of drinking water. The round ends with the halting of PIM in 2000. In the course of the 1990's the demand for drinking water stagnates. This raises the question whether PIM is still necessary in the short term to supply drinking water and to decrease groundwater extraction. Should PIM still be carried out? The following analysis is based on publications of WOB (2000) that explained why PIM was stopped. The summarizing system diagram can be found in figure 7.5.

7.4.1 External influences and outcomes of interest

WOB identifies five external influences that changed the situation in such a way that action was needed.

1. Development of the demand for water. The demand for drinking water stagnated, mostly due to the success of water saving actions and the 'water flight' of farmers who started private ground water winnings because of the higher price of drinking water, caused by newly introduced taxes on ground water. Thus the urgency to build a new water winning and purification facility ceased to exist.
2. Development of new technology. Membrane and depth infiltration technology became proven. This technology makes it possible to build in units. Thus the capacity of the supply facilities can be better adapted to the prognoses of the demand.
3. Rise of the delivery of 'other' water (prepared for special industry needs) and related services. The demand for water 'suited to the use' rises. This leads to more 'on site' solutions to supply in local water demand.
4. Change of the interpretation of the 'River law'. The permit for PIM that was needed on the basis of the River law was drawn back by Rijkswaterstaat, because of the new interpretation of the law that building in a river bed should not be allowed. WOB however, was convinced that this permit should not have been drawn back. This caused for some delay in the construction of PIM.
5. Persistence of the limited permit space for the extraction of ground water.

They also considered (and analyzed when possible) the following external influences when deciding about halting PIM or not. But these influences were decided to not to be taken into account, for reasons that are explained below:

1. The future use of 'household' water. The use of 'household water was expected to grow, but since pilot projects were not finished yet, this development was not included in the decision.
2. Outbreak of the 'pig-plague'. There was a large outbreak of the pig-plague, for which was a large media attention. An issue that was raised was how this disease would influence drinking water consumption. The pig-plague however, had only a temporary effect on the drinking water use. Simply because pigs that died were replaced.
3. The coming into effect of the 'reconstruction law'. This law was mainly developed to concentrate pig-farms in clusters to spare the environment and to prevent spreading of diseases. The effect on the use of drinking water was not clear yet. Therefore this development was not included in the decision- making process.
4. Regulation concerning private ground water winning. This regulation was developed but the effects were not measurable yet. Therefore this development has not been included in the decision.
5. Liberalization of the drinking water market for large users. When the decision to stop PIM just came into effect. The consequences of this development, however, were still not clear. Therefore it was not included in the decision.

7.4.2 Strategies and tactics and outcomes of interest

The preparations for PIM were already made and even some construction work had taken place when the decision whether or not to continue PIM had to be made. The external influences that were described before offered the opportunity to reconsider PIM, since the urgency to construct the winning and purification facilities had diminished. A choice needed to be made between carrying out PIM or halt PIM and take other actions to make sure that there was enough drinking water supply capacity.

Tactics that were included in the decision to halt or to carry out PIM were the following:
1. Focussing more on account management and marketing instruments, mainly towards agricultural and industrial users.
2. Making agreements with the Province of Noord-Brabant.
3. Appealing in court to the withdrawal of the 'river law' permit.
4. Installing Rinse water regain units (STUs) at pumping stations to diminish WOBs private water use, i.e. to minimize the water needed to prepare clean drinking water.
5. Carrying out PIM as was planned.
6. Carry out a different PIM in future
    A. Downscaling PIM by using new technology for modular construction.
    B. Realizing PIM with a different construction of the basin, namely without a ring dike, in order to get the 'river law' permit.
7. Exchange of ground water extraction permit space between pumping stations and closing down or reducing the winning at less sustainable pumping stations.
8. Using the over capacity of neighboring drinking water companies.
9. Keeping the purchased grounds near Lith for future use and maintain the permits that already have been given.
10. Perform more research in order to be able to build a modular PIM in future.

7.4.3 Choice

The decision was made to halt PIM but to keep all options open for the future, thus a strategy was composed out of tactics 1,2,4, 6A,7,9, and 10.

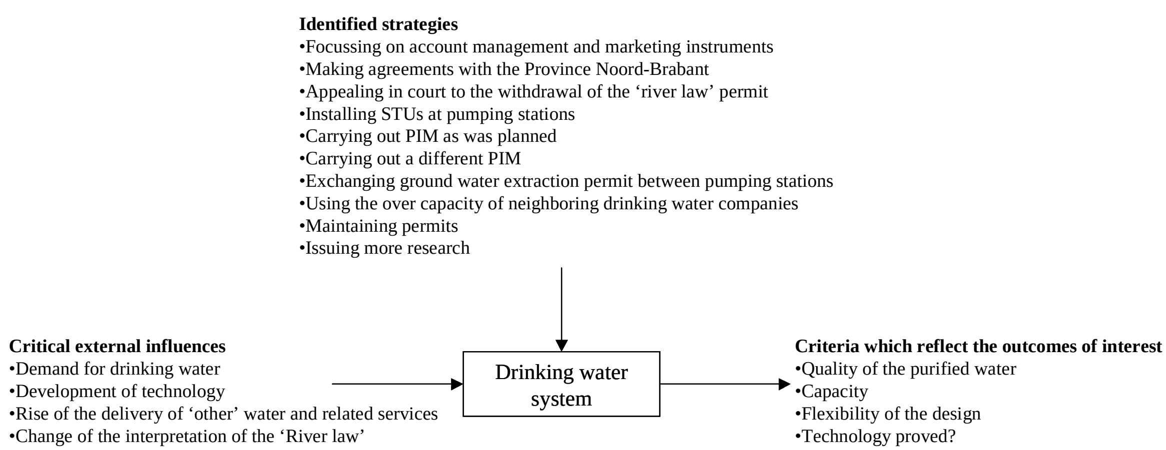

Figure 7.5 System diagram of round 2, 2000

7.5 Characterizing the rounds

7.5.1 System and relationships

The system boundaries that were chosen were consistent with the solutions that were considered. Also these system boundaries can be considered to be relevant to the problem throughout the whole project span, since solutions that were identified all concerned the identified problem and could be carried out to a large extent by WOB itself. The system boundaries, however, did not stay the same during the project. System boundaries were slightly changed when a new director was appointed. Where the most attention went to technological solutions to problems first, it shifted into a more broad view of what solutions would be wise afterwards. The new way of thinking about PIM coincided with this managerial change.

The potential success of water saving actions was an external variable that was not included in the decision-making process in 1990 about what strategy to follow to be able to supply enough drinking water in future. The reason for this was that not enough was known. This external variable is mostly social of nature.

The following external influences were excluded from the decision making process in 2000 about halting or carrying out PIM because not enough was known.

1. The future demand for 'household' water, i.e. water of less than drinking water quality for household purposes.
2. The coming into effect of the 'reconstruction law'.
3. Regulation concerning private ground water winning.
4. Liberalization of the drinking water market for large users.

Three of these external influences (2 to 4) concern the effects of political decisions outside the control of the drinking water company. The first, social, variable can be influenced more or less by decision of the drinking water company: when household water is not offered to consumers, they cannot use it.

It seems to be difficult to estimate the effects of political or social external influences, even if they are detected before their influence is measurable. The external variable, water saving actions, that was left out of the decision making process in 1990, because potential effects could not be estimated, was included in the analysis and decision-making process 2000, since better ways of estimating the influence of this variable became available. This indicates that there is a learning process present about how to estimate the influence of external influences.

7.5.2 Inputs and outputs

External influences that were included in the analysis mostly concerned demand related issues, which are pretty well known. If other external influences were mentioned in reports they usually were followed with the statement that not enough was known about them to include them in the analysis. Often such factors were not mentioned again in the rest of the report. External influences which are not included in the analysis are usually those that (initially) are not easy to quantify. In general no 'What if' and scenario analyses were used in a devil's advocate approach to know how a certain tactic would hold in a different future than expected.

Far more external influences are identified explicitly in 2000 than in 1990. The treatment of the identified external influences does not differ for both rounds: the external influences that can be quantified have more chance of being included in the decision-making process than those that are more of a qualitative nature or of which not enough is known to be calculable.

In 1990 technological tactics are in the center of attention, while in 2000 also other tactics, mainly aimed at other stakeholders, are considered while formulating a strategy.
Of the external influences that had a large influence on the decision to halt PIM, only one was noticed in 1990, namely the success of water saving actions. The rise of membrane filtration,

the changing interpretation of the 'river law' and 'water flight' were not foreseen. These external influences are technological, political and social of nature.

7.5.3 Assumptions

The assumptions that turned out to be correct are more common then those that prove to be incorrect. Most assumptions and analyses concern demand and influences on demand. Tragically, one of the most critical assumptions turned out to be wrong, namely about the development of the water demand.

7.5.4 Options

The decision that was made in 1990 to carry out PIM was largely grounded on the constraint that the technology employed should be robust with respect to the quality of the product but also with respect to the rise of the water demand. Two tactics that were not included in the 1990 analysis concerned new technology, namely membrane and depth infiltration technology. At that time it was not certain whether these technologies would be beneficial. In ten years time these technologies proved to function very well and also the cost for membrane applications lowered.

As a result, in 2000, the new technology opened the 'option' to combine this robustness with the flexibility of building in modules. This was one of the motivations to halt PIM, even more since the sense of urgency was no longer present when the water demand stabilized. This behavior can be characterized as risk-averse, but open to new ideas and opportunities as they present themselves.

An other example of the inclusion of robustness in a design was that WOB included the option of using river water from two different river basins, so that if one of them would become polluted the other source would still be available.

The option of buying time is used to the full when possible. The decision to start PIM was only taken when the critical point was reached that the full capacity would be used within the planning time of a new to build facility. In 1990, water demand was expected to be as high as the full ground water extraction capacity in 2000!
In 2000 when PIM was halted, also the option of buying time was included in the decision. The decision was made to maintain all permits and keep the purchased land near Lith to be able to decide to use these site in future for the winning and purification of surface water when necessary.

Chapter 8. Case 2. OEDI

He who predicts the future lies even if he tells the truth.
Old Arab proverb

This case study concerns the OEDI project of NV Waterleidingbedrijf Midden-Nederland (WMN). OEDI stands for **Oe**ver-**Di**epinfiltratie, riverbank- depht infiltration in English. This project was started to enable WMN water from the Amsterdam-Rijn channel for the preparation of drinking water, where traditionally groundwater is used.

WMN delivers drinking water in almost the whole province of Utrecht (see figure 10.1). Traditionally WMN is a self-winning groundwater drinking water company. Only a small fraction of the drinking water delivered used to be bought from or sold to neighboring companies. Recently this has been changed, since water now is bought from Hydron Flevoland. The agreement about this delivery is called the ROL agreement.

Figure 8.1 Service area of WMN (white)

Most of WMN's drinking water is supplied to households. Household demand is expected to increase the coming years even more since a large new residential area called 'Leidse Rijn' is being realized. Next to drinking water WMN also delivered a small amount of household water (which is of a little less quality than drinking water and can for instance be used to flush toilets) and process water, which for instance can be used as cooling water. The delivery of household water is being questioned with respect to public health since some residents of Leidse Rijn were abusively connected with it to their drinking water taps instead of to their toilets. Recently this household water delivery has been stopped.

The first of April 2001 WMN formed a cooperation with the companies FDM (Flevolandse Drinkwater Maatschappij) and WZHO (Watermaatschappij Zuid-Holland Oost). After that the company was renamed to NV Hydron Midden-Nederland. In this case study however the name WMN will be used to indicate that the events that are described all took place before 2001. Core facts about WMN can be found in table 8.1.

Table 8.1 Facts about WMN

NV Waterleidingbedrijf Midden-Nederland (WMN)		
Service area	Province of Utrecht, except for Doorn, and the town of Hilversum and the village of Scherpenzeel. The largest city in the area is Utrecht (see figure 8.1)	
Neighboring companies (until 2001)	PWN Waterleidingbedrijf Noord-Holland, Waternet, NV ENECO Energie Amstelland, and FDM (north), WZHO (west and south), and NUON and Waterbedrijf Gelderland (east and south)	
Bulk contracts	Purchase from Hydron Flevoland and Vitens (ROL contract)	
Water source	Groundwater	
Total amount of water delivered [1]	81 million m^3 (2000)	
Customers (2001) [2]	Small users	75%
	Middle large users	24 %
	Large users	14 %
# Connections [1]	500 thousand (2000)	
Shareholders	Province of Utrecht and the municipalities in the area. The province of Utrecht owns just as much shares as the city of Utrecht. None of the shareholders has a majority	
1. NV Hydron Midden-Nederland, 2001); 2. VEWIN, 2002		

8.1 Historical description 1972-2000

The OEDI case shows a lot of similarities with the PIM case. OEDI also was started as a result of a growing national concern about groundwater extraction possibilities in future and the aridification issue. See 7.1.2 for a more detailed description. The province of Utrecht translated the national plans into concrete goals in their water management plan of 1992. The most important one for WMN is that the permits for total amount of groundwater that is extracted will be limited with 25% compared to reference year 1985.

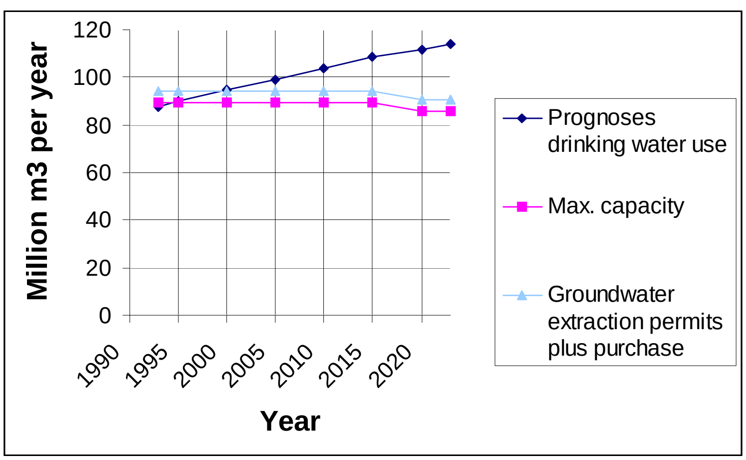

Figure 8.2 Prognoses drinking water use and maximum capacity of WMN in 1992 (WMN, 1992)

This policy had large implications for WMN since no more permits would be granted for extra ground water extraction. The available permit space plus contracts for the purchase of water from neighboring drinking water companies at that time was 94.4 million m^3 per year.

This made the maximum capacity of the WMN water works 89.7 million m^3 (see figure 8.2)[2]. At the same time they expected a growth of the drinking water demand of approximately 1% per year to 114.1 million m^3 in 2023. This would result in a water shortage from 1995 on.

WMN felt that action should be taken to be able to supply as much water as would be demanded in future and to diminish the aridification problems. Several alternative tactics were compared, of which most were based on a list of options provided in the Policy Plan Drinking and Industry Water Supply. These were the use of ground water, the use of river bank water, the use of basins and direct purification of surface water, open surface water infiltration and depth infiltration. These tactics are compared to a tactic called OEDI which combined some of the above tactics (WMN, 1996). From this comparison the conclusion was drawn that the use of groundwater was preferred, the second best option was OEDI. Because the use of ground water had to be limited, OEDI was the best option for WMN to meet a growing water demand. In 1992 the decision was made that OEDI should be developed. The environmental Impact Assessment (EIA) for this project was finished in 1996 (WMN, 1996). The project was expected to cost ƒ175 million (+/- € 80 million).

The OEDI concept in short consists of the following way of water winning, purification and distribution (WMN, 1996):

1. Water is won near the river Lek or Nederrijn, at a short distance of the river to prevent mixing with groundwater. The product of this winning is river bank filtrate.
2. This water is pre-purified to drinking water quality, without the guarantee of bacteriological and virological quality.
3. The water is transported to an existing pumping station at the Utrechtse Heuvelrug and infiltrated in the ground with depth infiltration.
4. After some time, the water is won back with the existing pumping station and after final treatment it is distributed through the existing distribution works.

Soon after some other alternatives were considered in the provincial Management Plan Groundwater Quantity (Provincie Utrecht, 1996): Buying water from FDM, minimizing groundwater winning in aridificated areas and maximizing groundwater winning in not aridification prone areas. These options are found to be less expensive and more efficient in attaining the wanted goals. However, still surface water winning was expected to be necessary since Flevoland would not be able to supply enough water. In 1997 the province permitted the start of OEDI and the preparations for realization of the project were started.

The benefits of OEDI for the aridified areas was questioned and projects like 'Goed water centraal' are started to find out what are the best options to fight aridification. Goed Water Centraal is a project in which the province, WMN and the water boards and nature preservers in the area take part. Conclusions were presented in 1998 (Goed water centraal, 1998). One of the important conclusions of this study is that regional measures to lessen aridification, like changing the groundwater use, are only effective in combination with local measures, like changing surface water management. These local measures were found to be the crucial factor in the fight against aridification. With this project the doubt rises if OEDI is such a good idea, since the study does not show that the use of groundwater should be stopped. In the study that followed, 'Replacing Production Capacity' (WMN, 2000), this doubt is reflected as follows: 'The project 'Goed water centraal' showed the importance of custom fit solutions and initiated

[2] The maximum capacity has been corrected for losses during the drinking water purification process. This so called self-use of drinking water was approximately 5% in 1990.

the doubt of the effectiveness of lessening ground water winning. Does the benefit for nature weigh up to the social cost?'.

An additional development is the stagnation in the growth of drinking water demand in the 1990's, a development that can be seen in the whole of the Netherlands. In Utrecht causes are the late finishing of the residential VINEX developments and the success of water saving actions.

To investigate whether OEDI should be continued two studies were started. One by the Province and one by WMN. The first was about the effectiveness of the proposed reduction of groundwater winning with 9 million m^3. The second was about acceptable and cheaper alternatives for the production of drinking water than OEDI, which are using groundwater and combining river bed water with membrane purification, a new and upcoming technology (WMN, 2000). As a result of these researches, the OEDI project is halted. Reasons are the uncertainty about the utility of the project and to create the opportunity to do research on further options. In the meantime water is bought from Hydron Flevoland to fill the gap between demand and the production capacity of WMN.

Historical overview

Period 1972- 1992	*Continuing growth of drinking water demand, translation of national goals with respect to aridification into concrete actions on a provincial scale*
1972	National drinking water scheme: limits to groundwater extraction, first mentioning of PIM
1992	Provincial Water Management Plan: National goals with respect to aridification are translated into actions, standstill of groundwater extraction capacity with reference year 1987, no extra groundwater extraction permits are granted
Period 1992- 2000	*Detailing of OEDI*
Period 1990- present	*Drinking water demand comes to a standstill, new technology for drinking water preparation becomes proven*
1992	WMN decides to develop OEDI
1996	Provincial Management Plan Groundwater: alternatives for OEDI are considered
1998	Report Goed Water Centraal: alternatives for OEDI are considered
2000	Halting of OEDI, WMN buys water from Flevoland until a better solution is found

8.2 Selection of important rounds

Two rounds were selected to be studied further. The first round that will be studied is the round that started with the awareness that drinking water demand was growing and without further action demand could not be met with the available groundwater supplies. This round ends with the choice to implement OEDI in 1992. The second round begins with the publishing of the first official document in which alternatives for OEDI are considered, the provincial groundwater management plan in 1996. The round ends with the halting of OEDI in 2000.

The sources of evidence for the analysis of round 1 are the environmental impact assessment of OEDI (WMN, 1996) and interviews. The sources of evidence for the analysis of round 2 are Goed water centraal (1996), and the rapport about replacing production capacity (WMN, 2000) and interviews.

8.3 Round 1: Selection of tactics, 1972-1992

Two developments made a search for new sources of water necessary: the growth of the demand for drinking water demanded capacity expansion, and the legislation on aridification made it impossible to extract more groundwater, which had always been used as the source for drinking water. This round is about which new source for drinking water WMN should use and what technology would be wise to implement. The summarizing system diagram can be found in figure 8.3.

8.3.1 External influences and outcomes of interest

Two external influences were important in the decision to start OEDI. First the legislation on aridification and second the expectation that the demand for water would grow as a consequence of autonomous reasons, but also as a consequence of the growing number of customers at the VINEX locations that were planned in the service area.

8.3.2 Strategies and tactics and outcomes of interest

In the environmental impact assessment of OEDI (WMN, 1996) the following tactics are compared to each other:

1. Use of semi-confined groundwater
2. Use of phreatic groundwater
3. Use of river bank water
4. Use of river bank water combined with depth infiltration: OEDI
5. Use of basins (natural)
6. Use of basins (constructed)
7. Direct purification of surface water
8. Open surface water infiltration
9. Depth infiltration

The choice for OEDI was based on a multi-criteria analysis in which the tactics that were identified were evaluated. This multi-criteria analysis reflects the outcomes of interest to the drinking water company. The following criteria were used to evaluate the benefits of each of these tactics: public health, environment, nature, landscape, spatial use, technological feasibility, flexibility, vulnerability, economics, administrative/ juridical aspects. Flexibility is defined as the ability to react to changing future circumstances, mainly with respect to the demand for water. Vulnerability is determined by the chance for cut off of the drinking water supply, in terms of quality and quantity and the consequences of such a cut off. The criteria that were considered to be the most important were nature and public health.
The use of semi confined groundwater scored very high on most of the criteria, except for nature. OEDI was scored fairly on most criteria, just like the use of river bank water. But in the light of the higher ranking of nature and public health OEDI was preferred.

8.3.3 Choice

The most favorable tactic was the use of groundwater (tactic 1), but since the use of groundwater had to be reduced due to provincial plans, the second best option was chosen: OEDI.

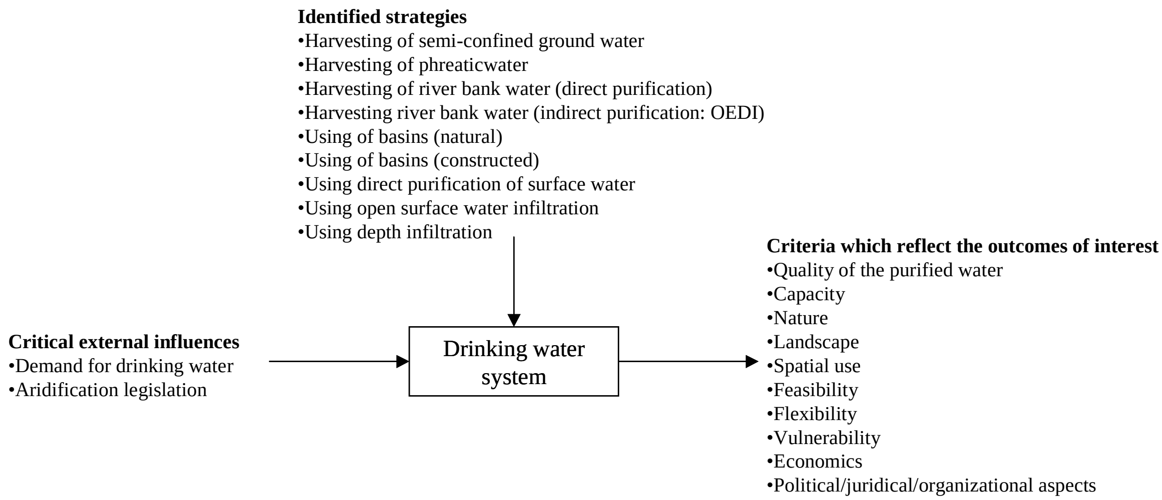

Figure 8.3 System diagram of round 1, 1992

8.4 Round 2. Halting OEDI, 1996-2000

The demand for water did not grow as expected and doubts about the benefits were ever present. This round starts with the publishing of the first official document with alternatives for OEDI in 1996, the provincial groundwater management plan, and ends with the decision to halt OEDI. The summarizing system diagram can be found in figure 8.4.

8.4.1 External influences and outcomes of interest

Two developments were important in the decision to halt OEDI. First the demand for drinking water stagnated due to the success of drinking water saving actions, but also the development of the VINEX areas got delayed. Second, there was still some doubt about whether OEDI was the best available tactic. Not all opinions were the same on this topic and extra studies were performed about what the right course of action was. This resulted for instance in the reports 'Goed Water Centraal' (Goed water centraal, 1996), and 'Replacing Production Capacity' (WMN, 2000).

8.4.2 Strategies and tactics and outcomes of interest

Next to the nine tactics that were already stated at the first decision-moment several other tactics are identified as possibilities to reduce aridification and compared to the tactics that were identified at round 1. Thus the following tactics were considered in this round.

1. Buying water from FDM
2. Minimizing ground water winning in vulnerable areas, maximizing winning in not aridification prone areas.
3. Use of semi-confined groundwater
4. Using river bank water and conventional treatment
5. Using river bank water and membrane purification (with and without mixture with treated groundwater)
6. Buying water from WRK and conventional treatment (Watertransportmaatschappij Rijn-Kennemerland
7. Buying water from WRK and membrane purification (with and without mixture with treated groundwater)

8. Direct purification of surface water with membrane technology (with and without mixture with treated groundwater)
9. OEDI

The tactics were scored (WMN, 2000) on the following criteria: Investment and exploitation cost, pubic health, operational management, the state of technology, environment, possibility to divide a tactic in phases, realization time. Of these criteria cost and public health were considered to be the most important, followed by environment. An interesting detail is the operational safety which is defined by operational safety and robust purification is weighed with a factor 1: 3 in respect to cost and public health.

8.4.3 Choice

Doubts about OEDI rose with the "Goed Water Centraal' study. OEDI was found to be a concept that could only be realized at high cost: two pumping stations had to be shut down and realization would cast much. Two technological alternatives were found to be cheaper and also socially acceptable, namely the use of semi-confined groundwater and the use of river bank water which is purified with membrane technology and mixed with treated groundwater. At the same time it became possible to buy water from Hydron Flevoland and together with re-allocation of capacity of pumping stations enough time was won to investigate further on the two promising technological alternatives. As a result the preparations for OEDI were halted.

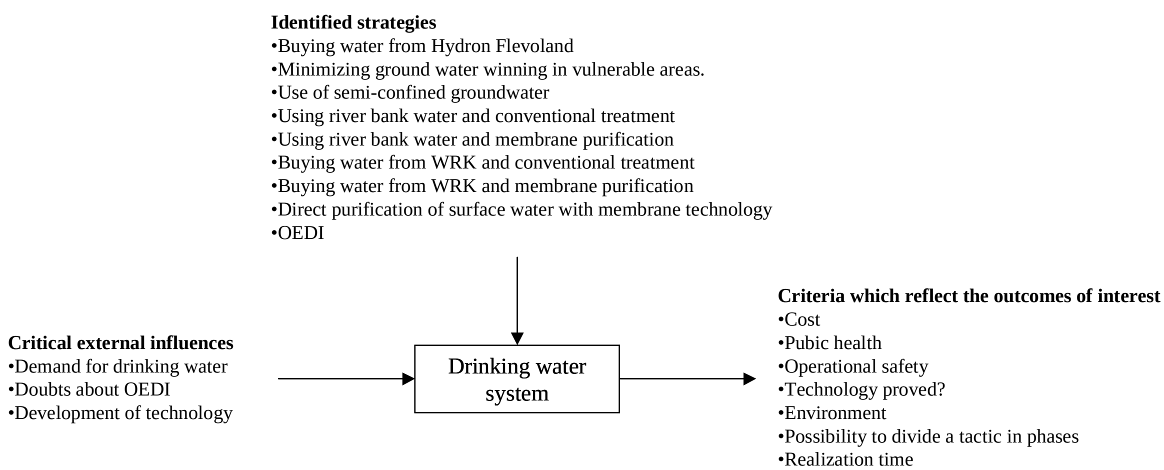

Figure 8.4 System diagram of round 2, 2000.

8.5 Characterizing the rounds

8.5.1 System and relationships

When the choice for OEDI was made, the system boundaries were chosen so that WMN could extend water winning capacity without needing other drinking water companies. Later, by including the tactic to buy water from Hydron Flevoland, the system boundary was broadened.

In the EIA (WMN, 1996) the use of groundwater was compared to the other tactics and scored best, but was dismissed explicitly. The reason was that the province demanded a stand still in ground water extraction. The creative use of groundwater reserves was, certainly in the second round, treated as being a serious tactic to prevent aridification, but also to be able to keep on using this source of water for the preparation of drinking water.

8.5.2 Inputs and outputs

The external influences that were important were mostly of political (pressure to reduce groundwater winning) and social nature (development of the drinking water demand). The tactics were to a large extent technological, but also buying water from others and re-allocation of groundwater winning were considered.
The outcomes of interest that were reflected in for instance the EIA (WMN, 1996) showed a great diversity. The identified tactics were scored on the criteria: public health, environment, nature, landscape, spatial use, technological feasibility, flexibility, vulnerability, economy and administrative and juridical aspects. A very broad range of criteria thus was used, of which six out of ten were not be quantified directly. This was solved by qualitatively determining the effects of the tactics by comparing them to each other. Thus scoring them ordinal with a score of 1 for the best tactic and 8 for the worst, which is a way of ranking that can be disputed since it does not reflect that some tactics may score very good or bad compared to others.
The deliberations in the second round were made in more or less the same fashion. More attention was given to the monetary cost of the tactics. Criteria reflecting uncertainty awareness like flexibility and vulnerability were removed and replaced by criteria operational safety and the possibility to realize the tactic in phases, which also reflect uncertainty awareness, but on a more operational level.

8.5.3 Assumptions

A critical assumption that not turned out to be true was about the speed in which the VINEX locations were be realized. This external variable of political/ social nature is very difficult to plan for, since a drinking water company is supposed to be ready for such developments, while at the same time they do not have influence on it.
This is a perfect example of how other actors can influence the effectiveness and efficiency of decisions that are made by drinking water companies.

8.5.4 Options

An option that was used was the option of buying time. WMN buys water from FDM, thus allowing further research on alternative options. OEDI was chosen since it was based on robust, mostly proven technology. An interesting detail is that flexibility (with respect to changes in drinking water demand) was a specific criterion in the first choice to realize OEDI.
Investing in knowledge is done throughout the entire case. Ever since the 1970s research has been done by WMN on the OEDI concept. Presently, research is being performed on alternatives for OEDI.
The whole palette of possible options thus was used to try to get the preferred results. The choices in round one show a preference for investment in robustness, where the choices in round two show a preference for flexibility and keeping the options open for the future.

Chapter 9. Case 3. Purification facility Jan Lagrand

Solum certum nihil esse certi (The only certainty is uncertainty)
Pliny the Elder (Plinius major), Historia Naturalis, BK ii, 7

This case concerns the planning of membrane purification facility Jan Lagrand by NV PWN Waterleidingbedrijf Noord-Holland (PWN). This project was mainly started to be able to provide soft drinking water without high sodium contents.

PWN delivers drinking water to the largest part of Noord-Holland. Amsterdam has its own drinking water company Waternet (former GWA, Gemeente Waterleidingen Amsterdam).

Figure 9.1 Service area of PWN (white)

PWN traditionally is a surface water company which infiltrates water from the river Rijn in the dunes. Because of this the company also has the task in maintaining and preserving the dunes in Noord-Holland. The province of Noord-Holland is one of the shareholders of Watertransportmaatschappij Rijn-Kennemerland (WRK) of which PWN it buys pre-purified river Rijn water.

PWN cooperates with Duinwaterbedrijf Zuid-Holland (DZH), Waternet and WRK with respect to their laboratory activities in 'Het Waterlaboratorium'. The cooperation takes place with respect to for instance the buying of appliances and laboratory matters. In the future a merger with the partners in this cooperation is conceivable. Core facts about PWN can be found in table 9.1.

Table 9.1 Facts about PWN

NV PWN Waterleidingbedrijf Noord-Holland (PWN)	
Service area	Province of North Holland, except for the Amsterdam and Hilversum areas. Large cities are Haarlem and Alkmaar (see figure 9.1)
Neighboring companies	Waternet, Hydron Midden-Nederland, Hydron Flevoland, Eneco Energie Amstelland, DZH, and Hydron Zuid-Holland
Bulk contracts	Supply to and purchase from Waternet, demand of pre-purified water from WRK
Water source	Surface water from the river Rijn infiltrated in the dunes or purified using membrane filtration
Total amount of water delivered [1]	102.8 million m^3 (2000)

Customers (2001) [2]	Small users	70%
	Middle large users	21 %
	Large users (including bulk sales)	9 %
# Connections [1]	685 thousand (2000)	
Stockholder	Province Noord-Holland	
1. PWN, 2001; 2. VEWIN, 2002		

9.1 Historical description 1973- 1999

In 1973 PWN starts an exploratory study on the use of membrane filtration. This new technology is used in the United States of America for desalinization of water for nuclear power plants. A large advantage of the technology are is extreme purification rate. However, there was little experience about the use of these membranes. In 1979 PWN starts to do research with a test installation in their purification facility in Andijk. In 1989 Jan Schipper a researcher from KIWA performed a PhD research on the subject. However, soon after the start, the research is stopped because of the lack of trust in the technology and the expected difficulties during operation.

In the 1980s PWN is confronted with three unfavorable developments. First, the demand for drinking water keeps growing because of the growth of the number of customers. Second, the national policy on aridification stated that the use of groundwater should be limited to a minimum. For PWN this had as a consequence that the use of Dune water from Zuid-Kennemerland should be limited. Third, there were problems with the quality of the raw water source. The implementation of the Rhine Salt Treaty was postponed in 1988. This meant that the concentration of salt in the IJsselmeer and the Rijn would not be limited in that period. These salt concentrations would lead to a sodium content of the drinking water of four times above the norm of that moment if purified with the existing installations of PWN. Also, PWN wanted to soften the drinking water. The common technology for this would only add to the Sodium content of the drinking water. Finally, new measuring techniques showed the presence of pesticides in the raw water source.

It was clear to PWN that these developments had to be dealt with and in 1993 the official start was made with Project Zuid. This project consisted of three elements: the extension and innovation of purification facility Wim Mensink in Wijk aan Zee; the realization of a new distribution facility in Hoofddorp, and the realization of a new production facility in Heemskerk. This whole project cost approximately ƒ400 million (€180 million). Only the last part of Project Zuid will be described further.

The salt issue was the reason that the research at the test installation in Andijk was restarted in 1990. PWN initially decided to built the new purification facility with a five step approach, which would include Hyper Filtration (HF), rapid sand filtration, disinfection with Ozone, Advanced Oxidation Process (AOP), and active carbon filtration. In 1993 the order was put out to eight consultants to make design sketches for two purification streets, one with the five step approach and one with pre-purification and infiltration, thus keeping the option open till later to make a choice between the two.

Soon after that the combination of Ozone and AOP, however, proved in tests to cause concentrations of bromate of four times the allowed norm. A little later in 1993, two other options were added to the list of possible options to PWN, namely a two step purification in which HF and Ultra Filtration (UF) were combined, and a three step purification which was a combination of Micro Filtration (MF), HF, and Ultraviolet disinfection (UV). The consultant that was chosen from the initial eight, Witteveen and Bos, detailed also these options.

Eventually the five step approach was abandoned and the choice was made to use the UF/ HF combination. The benefits over the three step approach of MF, HF and UV was that the two step approach reached full disinfection. The necessity of this became clear when a Cryptosporidioses epidemic in the beginning of 1993 in Milwaukee USA diseased 400.000 people and killed 100. All options however proved to be too expensive to execute.

Since then more companies started to supply membranes. This led to lower prices and to more available options of what membranes to choose from. Therefore the UF/HF option could be realized after all. In 1995 PWN gave the green light for the actual construction of drinking water production plant Jan Lagrand.

The eventual building of the purification facility was delayed for a couple of reasons. First, the project team had difficulties about deciding on the actual lay-out of the factory. In the end the sketch for the factory was made on a paper napkin on the flight home from a trip to the USA that the project team made in 1994. Second, there were difficulties in finding a location for the facility. There were severe protests from farmers, who did not want to sell their land, against the initial building site. Eventually some land was bought from Corus, a large steel works in the area. The delays made that PWN could use the newest technology available at that time, namely Thin Film Composite low pressure membranes. In November 1999 the new purification plant was officially opened.

Historical overview

Period until 1990	*Continuing growth of drinking water demand, increasing wish to reduce ground water winning in the Dunes*
Period 1973- 1995	*Exploring research on the use of membrane technology*
1973	PWN starts an exploring study on the use of membrane technology for the preparation of drinking water
1988	Postponement of the implementation of the Rhine Salt Treaty
1989	Halting of the research on membrane technology
1990	Restart of the research on membrane technology for reasons of the bentazon affair in the late 80's and the postponement of the Rhine salt treaty
1993	Official start of Project Zuid
Period 1990-1994	*Consideration of several technological alternatives for the set-up of production facility Jan Lagrand*
1994	Decision on the set-up of production facility Jan Lagrand
Period 1994-1999	*Detailing and construction of production facility Jan Lagrand*
1996	Start construction of production facility Jan Lagrand
1999	Opening production facility Jan Lagrand, rounding off Project Zuid

9.2 Selection of important rounds

The following two rounds will be studied:

1. The round that led to the decision to build extra capacity (1988-1993) From the postponement of the implementation of the Rhine Salt Treaty, which was one of the main

reasons for the wish for extra purification, until 1993 when the decision was made to realize extra capacity.

2. The round that led to the decision between four types of purification processes for the new to build purification plant (1993-1994). From the moment that an order was put out to detail two possible options for the purification process of the purification facility that was to be built until the decision was made to realize Jan Lagrand as it is.

The study of these rounds is based primarily on a special about the Heemskerk purification plant in H_2O magazine (H_2O, 1999) and an article in Water Science and Technology (de Bruijn et al, 2002). The quality of this written information was not as good as that from the other cases. This made it not possible to reflect on all aspects as deeply as I would have wanted to. The case is still very interesting since thinking in terms of options played a very important role, and it is very interesting to investigate how this influenced decision-making.

9.3 Round 1. Building extra capacity? Late 1980s

In the late 1980s PWN is confronted with three problems: a rising demand for drinking water and the wish to reduce the groundwater winning in Zuid-Kennemerland ask for capacity expansion; the Rhine-salt treaty is deferred (1988); and improved measuring technology show that the Rhine and IJssellake water contain too much pesticides. This calls for action. The following paragraphs show the deliberations that were made while deciding what to do. The summarizing system diagram can be found in figure 9.2.

9.3.1 External influences and outcomes of interest

The analysis of the documentation and the interviews about the decision to invest in capacity expansion resulted in the identification of the following most important external influences that were included in the decision-making process and their effects:

1. Development of the demand for drinking water. The demand for drinking water was expected to rise because of the growth of the population in the area. PWN expected the demand for water to exceed the supply capacity. Therefore extra capacity was needed.
2. Deference of the Rhine salt treaty. Because the Rhine salt treaty was deferred PWN expected a growing amount of salt in the Rhine water. To be able to meet the Sodium norm, more salt needed to be removed from the water in the purification process.
3. Restriction of the infiltration capacity of the dunes. In the third nota Waterhuishouding a reduction of the amount of infiltration in the dunes was issued. As a result an investment in capacity expansion was needed to be able to meet the future demand for water.
4. New measuring technology detected too large amounts of Bentazon in the Rhine water. To be able to supply drinking water of good quality an investment in purification processes needed to be made.

9.3.2 Strategies and tactics and outcomes of interest

The following tactics were identified by PWN:

1. Investing in capacity expansion
2. Investing in research and development of new technology

9.3.3 Choice

The choice was made to make a master plan for capacity expansion, which they named project Zuid (tactic 1) and to invest in research on membrane technology as well (tactic 2).

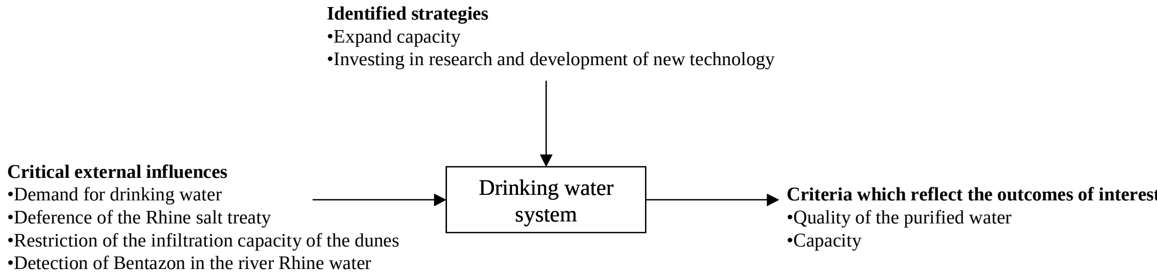

Figure 9.2 System diagram of round 1, late 1980s

9.4 Round 2. Which purification process? 1994

The capacity expansion PWN wanted to realize could be based on several technologies. This round is about what technology can be used best. The summarizing system diagram can be found in figure 9.3.

9.4.1 External influences and outcomes of interest

1. The arrival of more suppliers of membrane appliances. This development led to better products and lower prices of membrane appliances. Thus giving PWN more choices with respect to what technology to use.
2. Cryptosporidioses epidemic in Milwaukee. This epidemic led to a reinforcement of the awareness that double disinfection is a very important in drinking water purification. Regulation was established that enforced the use of double disinfection.

9.4.2 Strategies and tactics and outcomes of interest

The following technological concepts were explored:

1. Use of the 'old way' of purification: infiltration after pre-treatment. This approach led to a too high sodium concentration, certainly since chemical softening of the water lead to extra high Sodium levels.
2. A five step purification approach: Hyper Filtration (HF), rapid sand filtration, disinfection with Ozone, Advanced Oxidation Process (AOP), and active carbon filtration. Tests with this approach, however, showed too large quantities of Sodium and Bromate in the purified water.
3. A three step purification approach: Micro Filtration (MF), Ultra filtration (UF), and Ultraviolet disinfection (UV)
4. A two step purification approach: Hyper Filtration (HF) and Ultra filtration (UF). Tests with this approach showed that it provided a very good quality of purified water. But UF was never used before on the scale that was needed, and the combination of HF and UF never had been made.

The latter three options initially were very expensive. When more suppliers of membranes entered the market the prices of membranes lowered (see 9.5.2).

9.4.3 Choice

In 1995 the choice for the two step purification approach was made.

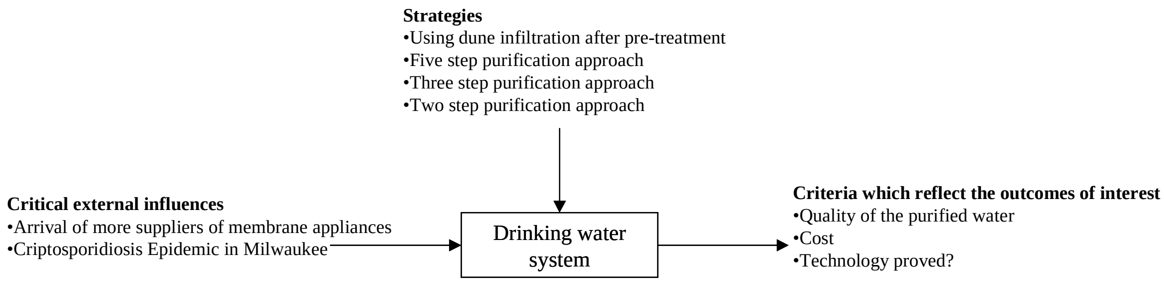

Figure 9.3 System diagram of round 2, 1994

9.5 Characterizing the rounds

9.5.1 System and relationships

The system boundaries remained the same throughout the entire project. The solutions that PWN could realize by themselves were leading in this. The system boundaries were relevant to the identified problem, which was also technological in nature.

9.5.2 Inputs and outputs

The external influences that turned out to be crucial for the motivation why choices were made as they were made were either technological, social or political in nature. Environmental or economical external influences did not play an important role. The fact that more infiltration in the dunes was not allowed was rather a political statement than an environmental external variable.

Tactics that have been mentioned were all of technological nature. Either because they concern a technological lay-out for a new to build purification facility or because they concern doing more research on technological subjects.

With respect to the outcomes of interest that have been mentioned, the quality and quantity of the purified water are in the center of attention and to a certain extent also the cost of the technological assets that were going to be used.

In conclusion it can be said that technological aspects were the most important elements that were taken into consideration in this project. This of course is a logical consequence of the fact that the planning of the Jan Lagrand facilities was part of a larger plan, namely project Zuid, which was not studied. In that plan it would be the right place to consider a more broad perspective.

9.5.3 Assumptions

One critical assumption did not turn out to be true, namely the assumption that the purification process needed to be improved to be able to comply to the norms for Sodium content in the purified water. The reason for this was that the Sodium norms were removed from European Drinking Water Directive (1998, 3 November (98-83-EC). Thereby one of the important reasons to construct a membrane facility disappeared, at least in juridical sense. The wish to deliver soft, less salty water remained, but it is no longer a boundary condition.

9.5.4 Options

Thinking in terms of options and smart choices with regard to the future played a large role in this project. All types of options can be recognized:

5. Investing in time. During the total planning of the project several technological concepts were developed in parallel which made it possible to make a choice for one of these concepts as late as possible, when more information was available, without losing extra time.
6. Investing in flexibility. The choice for membrane technology made it possible to build the purification plant in modules. This makes it possible to extend capacity relatively easily. Also extra space was reserved at the site of the plant for future expansion of the factory.
7. Investing in robustness. The choice for membrane technology did not only provide flexibility, but also robustness. This technology is able to remove the most tiny particles from water. Therefore it is capable to remove also substances from the water which are not known to be in the water and may cause harmful effects or harmful substances that will be in the water in future.
8. Investing in knowledge. PWN performed research on membrane technology from the 1979 onwards, when the technology was not widely spread yet. This research made it possible to realize a purification plant based on this technology when lower prices of membranes made it more attractive.

PWN shows to have a company culture that is very open to trying new things. They are willing to invest in options for the future even when it is not certain that the technology that will enable this becomes proven in time. Because they know that they run a certain risk they have contingency plans available. They worked on two technological set ups at the same time, thus allowing switching from the one technology to the other without a mayor loss of time.

Chapter 10. Case 4. The Lek-duin/ Maas-duin projects

That which has always been accepted by everyone, everywhere, is almost certain to be false. Paul Valéry, Tel Quel.

Figure 10.1 Service area of DZH (white), the dotted line marks the service area in 1956

This case study describes the decision-making process of DZH with respect to their Lek-duin and Maas-duin projects. These projects concerned the winning and transportation of respectively river Lek and Maas water to the Dunes. This case is more historical than the other three. In this way it can be studied whether the 'time spirit' has a significant influence on how uncertainty is dealt with and to what extent learning processes take place over time. At the start of this case, DZH was still called Duinwater-leiding van 's-Gravenhage and it served mainly the inhabitants of The Hague. In the course of time the service area was expanded to neighboring municipalities and reached its current size at January the first of 1996 with the take-over of the water production plant of EWR (Energie- en Watervoorziening Rijnland) (see figure 10.1).
The area is densely populated. It has approximately 1.15 million inhabitants. DZH mainly supplies drinking water to households. There is little industry to be found in the area. Exceptions are some large food concerns, for instance Heineken and Nutricia.
DZH prepares its drinking water from water from the dunes. In the past, the naturally present water was used. Soon however, more water was extracted than the rain could refill. Therefore, since 1955 river water is infiltrated in the dunes. After natural purification this water is pumped up again and purified further to drinking water. Core facts about DZH can be found in table 10.1.

Table 10.1 Facts about DZH

NV Duinwaterbedrijf Zuid-Holland (DZH)	
Service area	The Hague and surrounding municipalities (see figure 10.1)
Neighboring companies	PWN Waterleidingbedrijf Noord-Holland (north), Hydron Zuid-Holland (east), Waterbedrijf Europoort (WBE), currently named Evides (south)
Bulk contracts	Supply to WBE and Hydron Zuid-Holland and purchase from WBE and WATERNET
Water source	Water from the river Maas infiltrated in the Dunes

Total amount of water delivered [1]	83 million m^3 (1997)	
Customers (2001) [2]	Small users	61 %
	Middle large users	18.5 %
	Large users (including bulk supply)	19.5 %
# Connections [1]	357.5 thousand (1996)	
Stockholders	Municipalities in the service area. The Hague possesses the most stock, but no majority	
1. DZH, 1998; 2. VEWIN, 2002		

10.1 Historical description 1874-1996

Ever since 1874 in The Hague and its surroundings, dune water is used for drinking water. At first the natural fresh water in the dunes was used, but soon the demand outgrew the available amount of water. The refill by rain is 5 million m^3 per year. Expectations in the early 1930s were that the demand for drinking water would grow to 50 million m^3 water per year in 2000 (Gurck, 1956). At that moment it was 18 million m^3. A different solution was needed.

In 1932 the decision was made to investigate other alternatives. In 1939 it was decided to harvest water from the river Lek and transport this 45 kilometers, so that it could be infiltrated in the dunes, thus purifying it to drinkable water. DZH knew that the quality of the Lek water was far from ideal, because the water was polluted.

In 1955 the infrastructural facilities for winning, pre-purification and transport of Lek water to the dunes were taken into use. It cost ƒ18 million (+/- 8.2 million Euro). In that time, this was a large amount of money, but it was expected that this investment would secure the drinking water supply for quite a while. It was expected that The Hague would need 35 million m^3 water per year and surrounding municipalities 15 million m^3. The Lek-Duin infrastructure was able to provide that much.

Soon, however, the quality of the Lek water got worse. Also estimations were that the water demand of The Hague and its surroundings would become 100 million m^3 per year (see figure 10.2).

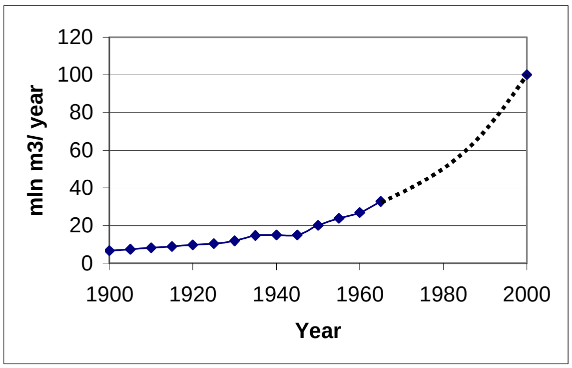

Figure 10.2 Drinking water use of the Hague and surroundings until 1965 and estimations from 1965 to 2000 (dotted line) (Gemeente 's-Gravenhage, 1968)

Again action was needed. This solution was found in the winning of river Maas water, for which the Afgedamde Maas[3] was used as a basin. In 1965 this plan was first described. The cost was estimated at ƒ 92 million (+/- 41.8 million Euro). The first phase of the project, the transport Infrastructure from the Afgedamde Maas to Bergambacht, would cost ƒ20 million

[3] The Afgedamde Maas is also called the Andelse Maas

(+/- 9.1 million Euro). The second phase, doubling and renewal of the existing infrastructure from Bergambacht to the dunes, ƒ72 million (+/- 32.7 million Euro).

In 1976 the first phase of the Maas- duin plan was completed. The infrastructure was connected to the existing Lek- duin infrastructure. This had some benefits. In case of calamities on the river Maas, always Lek water could be used. Also it was not necessary to construct a whole new transport pipe and a pre-purification facility.

The capacity of the existing transport pipe, however, soon became too small. As a consequence, especially in Monster, local water of less quality had to be used to prepare drinking water. Therefore a second transport pipe was made that was finished in 1996 (phase 2 of the Maas- duin plan).

Historical overview

1872	Start of realization of the DWL (Duin Waterleiding) project
Period 1874-1955	*Exploitation of Dune water*
1939	Principle decision to realize the Lek- duin plan (1946 formal decision)
Period 1939-1955	*Detailing and (from 1949 on) implementation of the Lek- duin plan*
1955	Bringing into use of the Bergambacht waterworks
Period 1955-1976	*Use of the Lek- duin waterworks*
Period 1965-1996	*Detailing and (from 1972 on) implementation of the Maas- duin plan*
1976	Bringing into use of the Afgedamde Maas waterworks
Period 1976- present	*Use of the Afgedamde Maas waterworks*
1996	Bringing into use of the second Bergambacht waterworks

10.2 Selection of important rounds

The rounds that will be studied further are:

1. The round that led to the decision to use Lek instead of dune water (1932-1939). This round begins with the decision to investigate alternative sources for drinking water and ends with the decision to realize the Lek-duin plan
2. The round that led to the decision to use Maas instead of Lek water (1965-1972). This round begins with the first detailing of the Maas-duin plan when expectations were that the Lek-duin works were not able to provide the capacity and the quality of water that was needed in the near future. The round ends with the implementation of the Maas-duin plan.

These two rounds were selected because they concern two succeeding decisions about large investments that influence the functioning of the infrastructure for a long period. Because the decisions are succeeding, the correctness of earlier assumptions can be observed. Detailed descriptions are available about the available tactics at that time. These are Gurck (1956) and Gemeente 's-Gravenhage (1954) about the Lek- duin plan, and Gemeente 's-Gravenhage (1968), Duinwaterleiding van 's Gravenhage (1969, 1976) about the Maas- duin plan. This is very important since this is a largely historical case, which makes it difficult to interview people that can speak about the case from their own experience.

10.3 Round 1. Lek- duin, 1939

The beginning of the 20th century the demand for water rose and the natural reserve of dune water was almost used up. The drinking water companies in Amsterdam and Rotterdam were contacted, but they were not willing to cooperate in finding solutions. The surrounding municipalities, which in that time all managed their own watersupply, also had problems to meet the rising water demand. The Dune water company saw this as an opportunity. All these small companies were not able to find economically efficient solutions by them selves. This round concerns the choice from the tactics that were available to the Dune water company. The summarizing system diagram can be found in figure 10.3.

10.3.1 External influences and outcomes of interest

The following external influences play a crucial role in the decision-making process:

1. The development of the demand for drinking water of The Hague. The drinking water demand is expected to grow to 50 million m^3 per year.
2. The development of the demand for drinking water of surrounding municipalities. The assumption is that these municipalities will want water from the Dune water company when available.
3. The dunes, as a water harvesting area, were exhausted.

The effect of all these external influences is that action was thought necessary to keep providing The Hague with drinking water.

10.3.2 Strategies and tactics and outcomes of interest

Four possible solutions were considered to solve the growing water quantity problem:

1. The harvesting of ground water. This is not a good source for drinking water because of the high salt content.
2. Harvesting of surface water in the Zuid-Hollandse plassen area. The exact arguments for or against this source of water could not be identified from the available written documentation.
3. Harvesting of water from the Eemmeer that was being realized at that time. The Eemmeer was not ready yet. Therefore this tactic would take a relatively long realization time.
4. Harvesting of water from the river Lek. The quality of the Lek water is far from ideal, and it is not known how the quality will develop in the future. The assumption is made that it will not get worse, since upstream drinking water companies will also need it.

10.3.3 Choice

The fourth option, harvesting water from the river Lek, scores best if measured with respect to realization time and quality of the raw water source. In the available documentation, cost is not used as an argument for or against one of the alternatives. Plans are made to lead the water from the river Lek to the dunes and infiltrate it. An extra advantage of this plan is that the dunes can function as a buffer that can be used when Lek water has a unacceptable quality or if the transport infrastructure fails. Therefore it will not be necessary to realize a double transport pipe.

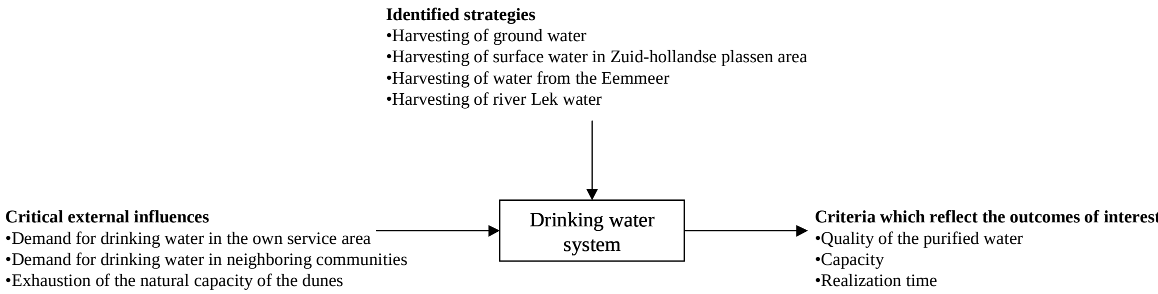

Figure 10.3 System diagram of round 1, 1939

10.4 Round 2. Maas- duin, 1965

Soon after the realization of the Lek- duin works, adjustments of the infrastructure are needed: the Lek water quality deteriorated and new estimations of the drinking water demand showed that the full capacity of the existing facilities would be reached in 1975. The described round concerns the choice between the tactics that were available to the Dune water company. The summarizing system diagram can be found in figure 10.4.

10.4.1 External influences and outcomes of interest

The following external influences were important in the decision making process:

1. The development of the demand for drinking water. The demand for drinking water was expected to be 100 million m^3 water per year in the year 2000. The full capacity of the infrastructure of 50.000 million m^3 water per year was expected to be reached in 1975.
2. The quality of river Lek water. The quality of the river Lek water was deteriorating and was not expected to get better and probably to get worse. Without action it would get more and more difficult to comply to the desired quality norms.
3. The quality of the river Maas water. The quality of the river Maas water was better than that of the river Lek, but also not very good. The assumption was that it would not get worse.

10.4.2 Strategies and tactics and outcomes of interest

1. Harvesting water from the river Maas. This tactic would cost ƒ20 million (+/-9.1 million Euro). In this tactic Maas water is infiltrated in the dunes instead of Lek-water.
2. Harvesting water from the river Linge. The river Linge does not carry enough water in summertime, but in wintertime the quality of this water is very good. Therefore this tactic could not be a solution to the problem by itself but it could be in combination with the Maas- duin tactic. It was considered to be a good option to implement later if the Maas water deteriorated.
3. Buying water from the Biesbosch of WBB (NV Waterwinningbedrijf Brabantse Biesbosch). The initial cost of this tactic is ƒ20 million (+/- 9.1 million Euro), but also a price per m^3 water would have to be paid. The capacity of the Biesbosch basins were almost reached at that time. When that would happen the Dune water company had to find another solution again, while it did not even need the basins of the Biesbosch because of the basin function of the Dunes.
4. Chemically purifying river Lek water. At that time the technology to chemically purify water was not proven yet. And large question marks were placed with its capability to purify river water to an acceptable quality with respect to salt content and taste. The cost of such a plan was much higher than that of the Maas- duin plan.

10.4.3 Choice

The decision was made to realize the Maas- duin plan and thus harvest Maas water from the Afgedamde Maas. The fact that the initial cost of a transport pipe from the Maas to the existing Lek- duin infrastructure was only ƒ20 million was decisive. The plan foresees in the possibility to also realize the Linge plan in a later stage. The transport pipe from Loevestein to Bergambacht therefore is planned to pass the river mouth of the Linge near Gorinchem.
The fact that a connection is made to the existing Lek- duin infrastructure has the advantage that in cases of calamities Lek water can still be used. In that way the Dune water company had two independent sources of water at its disposal.

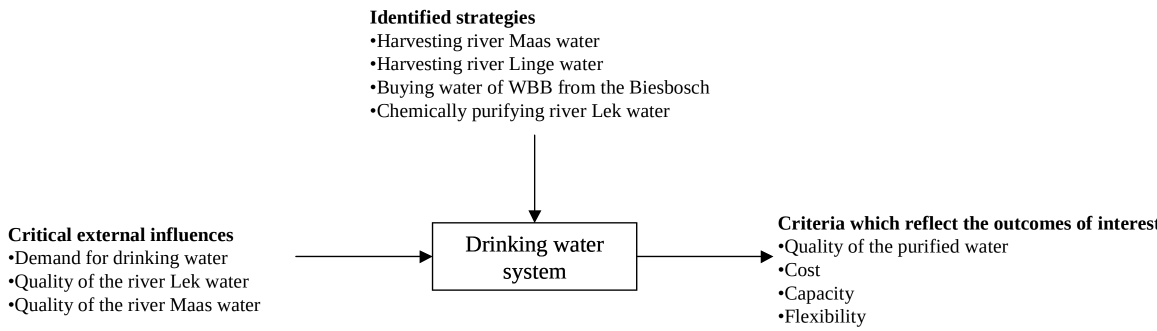

Figure 10.4 System diagram of round 2, 1965

10.5 Characterizing the rounds

10.5.1 System and relationships

The perception of DZH of the water supply problems and their way of searching for solutions were consistent. Solutions were searched for and found outside the own service area. Also DZH tried to cooperate with other drinking water companies to find solutions. Therefore it can be concluded that their focus in those areas was not too narrow.
The system boundaries that were chosen were relevant, since the solutions that were chosen could all be realized by DZH itself.

A good example of explicit inclusion of issues outside of the direct scope of the drinking water companies is the attention for the water supply problems of the neighboring small drinking water companies that had the same problems as DZH. By including their problem explicitly within the problem definition more solutions became available, since this allowed DZH to think 'bigger' and also consider solutions that were too expensive or large for only their own service area.

10.5.2 Inputs and outputs

The external influences that were identified were in social nature (growth of the number of connections, growth of the demand for water), of environmental nature (natural capacity of the dunes was reached), and of social/ environmental nature (deterioration of the quality of river water).

The tactics that were considered were mostly technological of nature, but also other types of tactics are considered as part of a strategy. Cooperation with other drinking water companies was looked for, buying water from the Biesbosch was considered as a serious option, and the delivery of water to other neighboring communities was included in the chosen strategy.

Tactics were mainly scored on quality, quantity, and cost.

10.5.3 Assumptions

The following assumptions about crucial elements in decision making did not turn out to be true:

1. Estimation of the development of the drinking water demand in 1939. The drinking water demand turned out to be much larger than expected.
2. Estimation of the development of the quality of the river Lek water. The quality of the Lek water deteriorated more than was expected.

These factors caused for the urgency to reconsider the Lek-duin water works infrastructure. Large investments were made with the idea in mind that the realized facilities would be sufficient for a longer period. This turned out not to be true. The Maas-duin plan dealt with these kind of misassumptions better by explicit inclusion of back-up options.

10.5.4 Options

In the Lek- duin and Maas- duin projects several options were mentioned and used, mainly having to do with robustness and flexibility.

1. Investing in robustness. The Lek- duin plan mentions buffering water in the dunes as a advantage that can be used when Lek water is unavailable due to quality problems.
2. Investing in robustness. Because of this buffering function the realization of two transportation pipes, which is considered as an option in the Lek- duin plan, is not necessary. This doubling of the transportation pipes becomes reality in the Maas- duin project.
3. Investing in robustness. As an advantage of the Maas- duin works the availability of two independent sources of water is mentioned.
4. Investing in flexibility. As an extra precautionary measure the option to harvest water from the river Linge is held open explicitly in case the quality of the river Maas water structurally deteriorates.
5. Investing in robustness. The Lek- duin plan reckoned with the extra need for water from neighboring communities. Its capacity was dimensioned in anticipation of this.

Chapter 11. Case study results

Who survives?
Not the strongest,
not the most intelligent,
but those who are most responsive to change.
Charles Darwin, 19th century English naturalist

In this chapter the case study results will be compared to each other to explore the possibility of more general conclusions. The comparisons of the case studies will be made according to the scheme that was also used to describe the case studies: system boundaries; system, sub-systems and relationships; inputs and outputs; assumptions; signposts; and options. Table 11.1 summarizes the findings. A plus ('+') is given when a certain aspect was found to play a role in the planning process of a drinking water company, when this aspect was not mentioned in their analysis a minus ('-') is given. When not enough information was available to know whether the aspect played a role the table shows a question mark ('?'). The findings will be illustrated with examples from the cases.

Table 11.1 Summary of findings

	PIM		OEDI		Jan Lagrand		Lek-duin/ Maas-duin	
System and relationships								
Relevance	+		+		+		+	
Consistency	+		+		+		+	
Shifting during the project	+		+		-		-	
Explicit exclusion of elements from the analysis	+		+		?		-	
Inputs and outputs								
Type of critical external influences	R1	R2	R1	R2	R1	R2	R1	R2
• Technological	+	+	-	+	-	+	-	-
• Societal	+	+	+	+	+	-	+	+
• Political	+	+	+	-	+	-	-	-
• Environmental	-	-	-	-	-	+	+	-
• Economical	-	-	-	-	-	-	-	-
Type of outcomes of interest reflected in criteria	R1	R2	R1	R2	R1	R2	R1	R2
• Quality	+	+	+	+	+	+	+	+
• Capacity	+	+	+	+	+	+	+	+
• Environmental impact	+	-*	+	+	n.a.	-	-	-
• Realization time	+	-	+	+	n.a.	-	+	-
• Cost	+	-	+	+	-	+	+	+
• Other	1)		2)		-		3)	
Type of tactics	R1	R2	R1	R2	R1	R2	R1	R2
• Technological	+	+	+	+	+	+	+	+
• Acquiring from other companies	+	+	?	+	-	-	-	+
• Going to court	-	+	-	-	-	-	-	-
• Reallocation of permit space	-	+	-	+	-	-	-	-
• Cooperation with other companies	-	-	-	-	-	-	+	+

Assumptions								
Type of failing assumptions								
• Technological	-		-		-		-	
• Societal	+		-		+		+	
• Political	+		+		-		+	
• Environmental	-		-		-		-	
• Economical	-		-		-		-	
Signposts								
Presence	-		-		-		-	
Options								
Presence	+		+		+		+	
Type	R1	R2	R1	R2	R1	R2	R1	R2
• Flexibility	-	+	+	+	n.a.	+	-	+
• Robustness	+	+	+	+	n.a.	+	+	+
• Time	+	+	-	+	n.a.	+	-	-
• Knowledge	-	-	+	+	n.a.	+	-	-

+ = was used in the motivation for decisions
- = was not used in the motivation for decisions or was not applicable
? = unknown
na = not applicable
R1 = Round 1
R2 = Round 2
1) i.e. Technology proved R1, Flexibility R2
2) i.e. Flexibility R1, Feasibility R1, Vulnerability R1/R2, Political aspects R1, Technology proved R2, Dividability R2
3) i.e. Flexibility R2
* Aridification was the starting point of the whole discussion, tactics were developed with this notion in mind

Not all rounds concern similar decisions. The rounds that were studied in the four cases were roughly divided into three groups, based on the type of decision the round ended with. The rounds that belong to the first group all ended with a decision about which alternative was preferred. Rounds that belong in this group are: PIM 1, OEDI 1, Jan Lagrand 2, Lek-duin/ Maas-duin 1+2. The second group of rounds ended with a decision to end a project, while considering other alternatives. Rounds that belong to this group are: PIM 2 and OEDI 2. Actually these rounds are comparable to the rounds in group 1 in the sense that alternative tactics are considered. But these rounds are special since a major previous decision is reconsidered. The last group contains only one round, namely Jan Lagrand 1. This round ends in a decision to invest, but it is not clear yet in what tactic. This distribution is shown in table 1.2. The rounds could have been divided differently, for instance by the amount of political pressure that was used by external actors. It was chosen not to do this because the analysis in this thesis concentrates on rational decision-making.

Table 11.2 Comparability of the different case study rounds

Groups	Rounds
1. Decision about which tactic to choose	PIM 1 OEDI 1 Jan Lagrand 2, Lek-duin/ Maas-duin 1 Lek-duin/ Maas-duin 2
2. Reconsideration of major previous decision	PIM 2 OEDI 2
3. Decision to invest	Jan Lagrand 1

It has to be noted that the rounds within the same cluster are not fully the same. Other actors are involved, decisions are made on different scales and on different tactics. For instance in the case of Jan Lagrand round 2 the decision was made to make a membrane purification facility. For this facility no Environmental Impact Assessment was required, since it had less spatial impact than for instance the PIM project. The scale of the system under consideration in the Jan Lagrand case was also smaller, since it was a part of a larger plan, project Zuid, which had an impact on the whole drinking water purification and transportation set-up of PWN. Table 11.1 therefore is not suitable to make conclusions by just comparing plusses and minuses. However, per group a general idea can be developed.

With regard to inputs, outputs and options a comparison can be made within the groups. For the other elements of the normative framework the interesting aspects concern the differences between the rounds within the same case.

Because the case evidence shows mostly similarities over the cases it was chosen to describe this evidence in a narrative way. In those instances where the cases did not support each other this was noted explicitly and where possible explained.

11.1 Systems and relationships

In none of the cases that were studied, direct clues could be found on how system boundaries were determined. However, no problems were identified that could be the result of setting irrelevant or inconsistent system boundaries.

Only indirectly the used system boundaries could be determined, by looking at the range of tactics that were used and the type of external influences that were identified. All studied projects concerned problems on the same scale. Usually the drinking water companies defined their system boundaries in a geographical sense. Nevertheless, not all system boundaries were (implicitly) similarly defined. Some companies looked for solutions mainly within their own region, where others, from the start, also considered solutions outside the own region.

Also, system boundaries did not always stay the same during the projects. In the PIM and OEDI cases they were clearly broadened. In these cases the broadening of the system boundaries led to the consideration of more tactics, and tactics with more option elements than before the broadening. The broadening of the scope in both cases was initiated when new opportunities came into the picture. This indicates that system boundaries were determined reactively and not consciously chosen before and then fixed.

The only two cases in which evidence was found that some elements were explicitly excluded from the analysis of the decision-making process are PIM and OEDI. This does not imply that it did not happen in the Jan Lagrand and the Lek-duin/ Maas-duin cases! In the PIM case, some external influences, like the effect of water saving actions, were excluded as being impossible to assess in a meaningful way. In both the PIM and the OEDI case the tactic to use more groundwater was pushed aside for political reasons.

11.3 Inputs and outputs

11.3.1 External influences

Table 11.1 shows that societal external influences are made explicit in the analysis as having much impact. This conclusion can be made for most cases that have been studied. This also is true for political developments, certainly in the recent cases.

In retrospect, the analyses used to choose between different alternatives were often not as rich as could be with regard to dealing with uncertainty. For instance, political and social forces were identified, but were often not included in decisions since not enough was known about them or because they were difficult to quantify.

When dividing the external influences in the five categories that have been identified in chapter 6, it appears that many external influences that turned out to be critical were political and social in nature. Nature as a category of external influences is much less important in the cases that were studied (except for in the Lek-duin case). All projects do deal with the attention for nature as an important external variable, but it is not so much nature itself that is the factor which makes nature an important factor. The political attention for this factor makes for instance aridification an important theme for drinking water companies.

In the PWN case, for instance, new regulation on infiltration was one of the reasons to restart research on membrane purification technology. In the OEDI case the groundwater depletion issues were the most important reason to start searching for alternative water sources.

External influences of a social nature include the growth of the drinking water demand, which is the most important external factor for drinking water companies. Influences can be for instance population growth or the success of water saving actions, which both have a social nature.

Economy is not mentioned in any of the cases as being a separate external factor of critical influence to a decision. Mostly however, economical projections are used in the estimations of the drinking water demand, mainly to estimate industrial demand.

The development of technology is an external variable that is followed with much interest. Technological developments are not so much seen as a threat, but rather perceived as creating opportunities. Not all drinking water companies however, are daring to take the step of implementing new technology out of fear of being to soon and getting stuck with infrastructure that does not function well, or of implementation or operating cost that unexpectedly get out of hand.

11.3.2 Tactics

Table 11.1 shows that when tactics that have been selected are reconsidered (group 2) this is explained with other criteria and arguments than the first decision. But there is no proof that these new arguments in general are more future oriented, which could be the case when thinking in terms of uncertainty becomes more important during a project.

In all cases and sub-groups that were included in table 11.1 technological solutions play a important role. Tactics in most cases that were studied were mainly sought in technological alternatives, that preserve the independent, self-sufficient nature of the companies. Initially, solutions are seldom sought in the political or societal arena. In the cases that were studied in which tactics were reconsidered, in the second round other types of tactics won more attention, like cooperation with drinking water companies or reallocation of permit space.

This can be a coincidence, because in the more historic Lek-duin case the search for cooperation was the first action.

11.3.3 Outcomes of interest

The outcomes of interest that get the most attention in all of the cases are water quality and quantity. These outcomes of interest reflect the 'core business' of drinking water companies.
The third most important outcome of interest is cost. The cost of alternatives is always investigated and though they play an important role they are not the decisive factor in the decision to implement a certain tactic. The best alternative with respect to qualitative and quantitative aspects is preferred, even when this increases cost. But: cost should stay within proportions. What these proportions are is subject of discussion. Not all drinking water companies share the same ideas about this.
Whether or not a technology is proven is a criterion that is always considered when choosing between technological tactics. It depends on the culture within a drinking water company whether this is an important argument not to choose for a certain tactic with potentially large benefits. PWN showed that they were willing to take the chance with membrane technology on a larger scale than was used before. Other companies, at the same time, thought that this would be too risky.

11.4 Assumptions

It was found that no systematic ways were used to make assumptions explicit and visible. Critical assumptions are sometimes, but not always, made explicit as being assumptions that may not come true. In the Lek-duin project for instance the critical assumption the river Lek would not deteriorate further was made explicit. However, despite this explicitness in this case no contingency plan was made. In the other cases sometimes contingency plans were made, for instance in the Maas-duin project which followed up the Lek-duin project.

The case evidence shows that making a wrong assumption can be an initiator for a learning process about that assumption. Drinking water companies do not want to make the same mistake twice. Two ways of action were found with regard to wrong assumptions. First, preventing wrong assumptions of being made: for instance finding better ways to estimate future water demand. For instance, in the early 1990s drinking water companies were not able to take the effect of water saving actions into account in their estimations of future drinking water demand. When more knowledge became available they included this in their calculations. Second, making sure that a wrong assumption will not have disastrous effects. An example can be found in the Lek-duin/ Maas-duin case. Two critical assumptions in the Lek-duin plan did not turn out to be true. First the drinking water demand was forecasted too low and second the quality deterioration of the Lek was not estimated well. The Maas-duin plan included some options that could be used when assumptions with respect to the demand and quality of the river water failed. These were, with respect to water quantity a plan to double the Bergambacht waterworks, which also would result in extra redundancy in case of calamities in one of the two transportation facilities. With regard to water quality, the drinking water company decided to lead the Bergambacht works passing the river Linge, which is an alternative source for water. In retrospect, this last option was never used, and nowadays would not be considered for actual implementation.

In all four cases the external influences that were found most difficult to estimate were all of political and social nature. This is not strange since these type of external influences can change suddenly and drastically. This can also be the case for economic external influences, but this was not seen in the cases. Influences of an environmental nature usually change more gradually, like for instance the exhaustion of the fresh water reserves in the dunes in the Lek-duin/ Maas-duin case. Changes in technological external influences do not have a direct influence on the system performance of a drinking water company. It is their own choice to comply with the newest finding or not. This may well be a reason in combination with others to reconsider a project, as happened in the PIM case.

Estimating future demand for drinking water is not easy. In all cases that were studied the future demand turned out different than expected. In the Lek-duin case the future demand was underestimated, and the demand in the OEDI, PIM and Jan Lagrand cases was overestimated. Only in the Maas-duin case the estimations turned out to be more or less correct. Lessard and Miller (2000) concluded the same thing in their analysis of sixty case studies of large technological projects. In many of the projects that were studied, projections turned out to be widely off the mark, despite the fact that often external experts were used to check projections. In some cases, errors resulted from shortfalls in overall economic growth; in others, because the structure of specific demand turned out different than anticipated.
De Bruijn et al. (1996) warn in their book on decision-making in large projects for making wrong estimations of future demand for instance caused by unsuitable research or too large optimism. They mention that for prestigious projects administrative arrogance can get the overhand, which makes the risk of overestimation of demand even larger. In the cases they studied they found that sometimes even positive prognoses were asked of bureaus that would fit with their preferred tactics. In the drinking water cases that were studied no evidence was found for this type of behavior.

There is a development towards more sophisticated ways of making estimations of the future drinking water demand. At first, one best estimate prognosis of the drinking water demand was made and used to determine the necessary dimensions of drinking water works. This can for instance be seen in the Lek-duin/ Maas-duin case. In the other projects of a later date that were studied, also bandwidths are determined around this best estimate. The next step is the thinking in terms of trend breaks, which is facilitated by thinking in terms of possible scenarios. This way of thinking is gradually being introduced in the drinking water world, as can be concluded from conversations with people from the drinking water world, but is not seen in the written documentation on the studied cases.

11.5 Signposts

In none of the cases evidence can be found that signposts are used. Monitoring of the drinking water demand takes place and external influences are followed and reacted to when this becomes absolutely necessary. However, no pre-defined thresholds are determined which trigger for action or the rethinking of decisions that were made before. The initiative for actions or reconsideration is totally dependent on the vision and alertness of individual people within the organization.

Some examples of how signposts could have been used in the cases are the following. In the PIM, OEDI and Jan Lagrand cases, membrane technology was in first instance perceived as being not proven and too expensive. A signpost for the proof of technology can be the successful use of the technology on a scale that is comparable to the needed one. When the technology actually is in full operation and an evaluation is available one can say that this technology has become proven. The signpost for the same external variable can be determined in different ways, depending on the preferences of the decision-makers. For instance, technology can also be considered proven when it proved to be successful on a laboratory scale and an evaluation report is available with respect to all possible side effects of the use of

the technology. This example shows that it will be sometimes difficult to come to an agreement on what signpost to use. A signpost for the cost of membrane technology is easier to imagine. One can set a yardstick at the price that one is willing to pay for the technology. When this threshold is reached one can decide to reconsider previous decisions.
The previous examples all reflect signposts that could have been used to identify opportunities. Mostly signposts are used to recognize threats. In the studied cases the signposts could have been used to mark the point when action was necessary with respect to declining demand for drinking water. For instance, a standstill or declining demand for drinking water in three consecutive years could have been a signpost that would trigger reconsideration of previous decisions.

11.6 Options

With regard to options it can be concluded from table 11.1 that at first robust solutions are preferred, in more recent times flexibility gains headway. However, it cannot be proven that the strive for flexibility is something new. Also in the historically oldest case the phenomenon can be seen. When the first solution did not prove to be satisfying people wanted to get more certainty by being able to switch between water sources.

All types of options that were identified in chapter 6 have been seen in one or more of the cases. This indicates that drinking water companies do include types of options when available.
When looking at trends and events that may have influence at the longer term, in all cases it appears that drinking water companies primarily strive for robustness. Regardless of the developments in the 'world outside' they want to be able to provide drinking water of very high quality. By building robust infrastructure they increase their independence. Investing in robustness has always been a part of the drinking water companies toolkit, which is shown in all cases including the oldest one, the Lek-duin case. Usually infrastructure components are over dimensioned.
Also, to a certain extent, drinking water companies strive for flexibility. For instance by reserving extra space to be able to expand the infrastructure at a later time. Usually, however, they will not aim for flexibility that may be won with the implementation of new, unproven technology. PWN is the one exception in this respect. When promising technology becomes proven, the initial caution is replaced by enthusiasm, as can be seen in the PIM case.
Postponing a decision until the last moment possible has been seen in all three recent cases. In the Lek-duin and the Maas-duin cases no evidence has been found that this happened, but it would not be surprising if it also happened there. Lessard and Miller (2000) observed that in many cases they studied there was an early investment in information search while commitments were low and the options many; difficulties were avoided by refusing to lock in early and by postponing choices as long as the value of information remained high.
Drinking water companies invest in the development of new technology. For instance, in the 1970's PWN and WMN invested in research about the technology they turned out using 20 years later. By such investments in research knowledge is gathered that can be used in a later stadium to make a well founded choice to use new or promising options in the future.

11.7 Planning processes and the outcome of the projects

Beside the case evidence that was found with the descriptive framework, also other aspects from the cases drew some attention and need mentioning. These aspects mainly have to do with case circumstances and the process in which the projects took place.

The cases that were studied concerned capital intensive projects of a magnitude uncommon to the companies that planned them. The planning of new infrastructure and new purification methods require large investments in monetary terms, but also in terms of time and effort of personnel. For OEDI a lot of time was spent on research. For PIM a lot of effort went to the preparation of the project. Also, the preparations of the Jan Lagrand plant required a lot of re-design efforts.

The projects that were studied in this thesis were not undisputed. Opinions about the benefits of the chosen technology and the cost involved differed. In the case of PIM and OEDI this eventually led to the halting of the projects.
There are indications that the attitude towards the projects of a small group of people within a company is of high influence to the eventual decisions. This group can make or break the projects. This does not mean that this is the only reason why the projects were stopped or carried through, but it does play a role. It is well known that for instance in the PWN case the vision of the company's executives was a determining factor for the courage to invest in unproven technology. In case of the PIM project a change of directors also meant a change in attitude towards the PIM project. An external stakeholder can also have a large influence on the decisions that are made. In the PIM and OEDI cases for instance the Provinces of respectively Noord-Brabant and Utrecht forced the drinking water companies to seriously consider other sources of water than groundwater.

Strategic use of external influences was also observed. External influences are mostly used to justify decisions that were previously made. For instance, in the PIM case to show why it was necessary to halt the project, or in the Jan Lagrand case to justify the decision for the use of membrane technology. The analysis of the possible future impact of external influences is seldom made a part of the decision preparation process, for instance in a 'devil's advocate' approach. The external influences are thus mostly studied as having had influence in the past and with regard to consequences for the present.

At the time that three out of four case studies took place the Dutch drinking water world faced movements towards drinking water companies of a larger scale. Mergers and cooperation agreements that in the Dutch drinking water sector since 2000 were the following:

- WOB and WNWB merged at January 1 2002 to Brabant Water NV.
- WG, WMO (Watermaatschappij Overijssel) and NUON merged at May 17 2002 to Vitens.
- WZHO, FDM and WMN cooperate in Hydron since April 1 2001.

Also in the time that the Lek-duin and the Maas-duin plans were developed DZH was in the middle of negotiations about mergers. Therefore it can be concluded that the decisions in all cases were probably influenced by thoughts about these developments. The influence of these developments is not always made explicit in the documentation that was available about the cases. WOB and WMN were partners in respectively a merging and a cooperation process at the same time that their projects were halted. In the motivation of decisions, however, this does not show. In the workshop that was organized to evaluate the research results it was mentioned that political motivations play a major part in such decisions. This, however, is usually not made explicit in resulting documents.

11.8 Dealing with uncertainty in the past and in the present

The added value of the studying of the Lek-duin and the Maas-duin cases is that this gives an impression of the difference between dealing with uncertainty in the past and the present. Basically not much has changed since those projects in the type of uncertainty that drinking water companies encounter and their reaction to these uncertainties. The most important change is the attitude of drinking water companies with regard to uncertainties. Where it used to be safe to assume a growing demand for water this is not true any longer. Even more, society demands efficient operation by all utilities, companies now more than ever. Drinking water companies therefore are also more pressured to underpin their decisions in that light. This brings about a greater awareness of uncertainties and a need and willingness to deal with uncertainties before decisions are made.

Chapter 12. Conclusions and reflection

..... once we see this fundamentally open quality of the universe, it immediately opens up the potential for change; we see that the future is not fixed, and we shift from resignation to a sense of possibility. We are creating the future every moment.
Joseph Jaworski (1996).

This chapter will reflect on how the research was performed and on the results that it generated. To this end, the consequences of the findings from chapter 11 will be elaborated on and compared to the results of a workshop that was organized to evaluate them. The lessons that thus can be learned will be translated into practical recommendations to drinking water companies. Finally, some reflections are made on how these results can be used in a more broad perspective and a reflection is made on different styles of uncertainty management.

12.1 Reflections on the research set-up and the theory that was used

Before the conclusions will be presented, first a reflection will be made on the research itself. The strengths and weaknesses of the research set-up, of the theory that was used for this research, and of the case study set-up are discussed. This is done to better understand the limitations of the conclusions that can be drawn.

12.1.1 Reflection on the research

The research was based on two activities: a literature study on dealing with uncertainty in planning processes, and a practical case study analysis. The set-up of the research proved to work well in that it made easy comparison of the cases possible.

12.1.2 Reflection on the descriptive framework

As a basic framework for analysis, a systems approach was used (see chapter 4). With such an approach problems or decisions are structured in system diagrams, by thinking in terms of systems, external influences, tactics and outcomes of interest. This approach theoretically has the following benefits: 1) The approach helps in structuring thoughts and issues; 2) Communication about problems and issues is made easier, because its provides an overview of the important elements in a decision situation; 3) When an issue has been structured it is fairly simple to identify possible critical uncertainties. In practice this proved to be true.
The use of system diagrams, on the other hand has proved to have some downsides and pitfalls. A systems diagram can indicate uncertainty that stems from political processes, but is not directly suitable to indicate the dynamics of political and administrative processes. A system diagram displays perceptions as seen at one moment in time. Dynamical influences thus are presented in a static way. This should be realized when interpreting a systems diagram, since otherwise changing elements can be interpreted as facts. This is dangerous since the dynamics in processes are the cause of many critical uncertainties that can be encountered.
To understand such dynamics, actor analysis can be a useful tool. Actor analysis or stakeholder analysis can be defined as an approach and procedure for gaining an understanding of a system by means of identifying the key actors or stakeholders in the system and their perceptions, and assessing their respective interests in that system (Grimble and Chan, 1995). Different types of actor analyses exist. Some of them can be used to better capture the dynamics of processes and actor interactions (Hermans, 2005). See for instance Grimble and Chan (1995) for the principles behind actor analyses and the opportunities they offer, and Hermans and Timmermans (2001a/b) for an overview of types of actor analyses. For this research it was not necessary however to go beyond the use of system diagrams, since

cases were studied ex-post and per case more systems diagrams were used to show changes over time.
As was mentioned, system diagrams present a rather static picture of reality in which network perspectives do not show. In the case of a study of drinking water companies interest in the drinking water system this is not a large problem. Drinking water companies have a natural monopoly position, and operate in a way that is more or less consistent with a single actor setting. This has the advantage that their reaction to uncertainties could be studied well. But, by studying only drinking water cases is was not possible to explore if the used approach of investigation could also be used in a multi-actor setting. The complexity that stems from other actors in the environment of a system can be described only to a certain extent with a systems diagram. When this complexity gets large, probably adjustments of the methods need to be made to maintain clarity for instance to describe relationships between actors and their influence on the specific elements of the system under consideration.
The (dis)advantages of the use of systems diagrams in multi-actor setting should be the subject of further research. In that research, for instance, other infrastructures can be studied, which are planned for in a totally different setting and for which more actors are involved in the decision-making process. A fact is that a systems approach does not illuminate risk management that is dominant in many day-to-day situations, like sharing responsibilities with other stakeholders or actors, the identification of possible actors with different opinions, management of daily events, relation and people management.

A system diagram can help in decision-making processes to prevent tunnel vision, because it stimulates to focus on more than one solution or objective. When not used properly, however, it can be a cause for it, because it provides too simple a picture of reality. A system diagram can only be used as a structuring tool to better understand situations. It should not be perceived as providing the one and only true picture of reality. Since it is used as a structuring tool different people may draw different pictures and even when this would not be the case not everything may be known.
A planning process usually moves on different levels of scale. An analytical proper working method in making systems diagrams for planning processes therefore would be to make different diagrams for different levels of scale. Issues at different scales can contradict each other and interact in a way that can never be captured in a single diagram that, for one decision, provides an overview over all levels of scale. In this thesis no separation was made, because this would result in much repetition in the system diagrams and an incomprehensible analysis. This is the reason that in the analysis for instance issues at a provincial level can be found in the same picture as issues about a specific piece of infrastructure. This did not cause problems in the analysis, since the analysis was done from the perspective of the drinking water company, its possible actions and its perception and knowledge of its surroundings.

The initial idea was to use system diagrams to describe the design issues for the technological system only. This would correspond to the way of thinking of drinking water infrastructure planners. However, many tactics that are available to drinking water companies, like insurance, going to court or pricing, are directed to elements outside the technical system under consideration. Therefore a more broad system perspective was chosen. However, to see whether drinking water companies use the whole range of tactics that are available to them it has proved to be a useful exercise to make a narrow focused system diagram. The tactics that were used were split into those that were directed at the technological system and those that were directed at things outside the technical system. The tactics outside the technological system were always within the influencing sphere of drinking water companies. For instance, going to court to enforce the granting of a permit and insuring against losses or sharing the responsibility for investments with other actors.

12.1.3 Reflection on the normative framework

The normative framework of indicators for successfully dealing with uncertainty was an effective help in identifying gaps between normative theory and practice. However, some theoretical concepts were very hard to make measurable. Even though the indicators that were used were as objective as possible, almost always an interpretation of the results stayed necessary. To prevent tunnel vision, the results of the case studies, both descriptive and normative, were shared with others both with and without knowledge of the cases. Thus it was tested whether the results would have been the same if somebody else would have done the analysis. The method proved to be valid.

Some remarks need to be made on the causal chain that was presented in chapter 5. This causal chain was taken as a starting point for the normative analysis. One of the research objectives was to find out whether this causal chain can be considered plausible. In the research as it was performed, no evidence was found that would suggest otherwise. The only remark that can be made is that there are other factors besides analysis that determine the choices of decision-makers, like political considerations or financial deliberations. These factors in many cases have a larger impact than analytical reasoning. Thereby it cannot be concluded that a good analysis with respect to uncertainty automatically means that uncertainty is dealt with well. However, it can be made plausible that it is a precondition for success in dealing with uncertainty.
A suggestion that was made in the workshop that perceiving uncertainty as coming from different sources and affecting the infrastructure in different ways should be a great help for people who want to improve their way of dealing with uncertainty.

12.1.4 Reflection on the case studies

Case study analysis proved to be a fruitful way of investigating how uncertainties have been dealt with in the drinking water practice. The systematic studying of cases contributed to the knowledge of where improvements can be found in the planning process of drinking water infrastructure.

The design of the case study part of the thesis had a number of implications for the results that could be gained. By making the choice to focus mainly on ex-post cases, also the choice was made to focus on the analytical part of dealing with uncertainty, since the main source of information on the cases was written documentation. In written documentation and even with interviews it is difficult to uncover the effect that the process of decision-making itself had on the choices that were made and thereby on how was dealt with uncertainty. A part of how drinking water companies dealt with uncertainty thereby was possibly not addressed.
In written documentation, mainly the choice between technological tactics is described. Economic and political tactics are not considered in these documents. This does not mean that they have not been considered at all. There may be various reasons why drinking water companies do not consider these tactics in their reports, like political sensitivity, consideration by other faculties in the company, or documentation in different documents, like minutes that are not open to the public. It is clear that this type of tactics were not fully uncovered in this research. Even when they are mentioned, it is very difficult to uncover the motivation for their implementation or their rejection. Initially it was the intention that these kind of tactics would get more attention than they have got eventually. With hindsight this proved to be troublesome, since the planning processes were already finished and these kind of tactics were

not always documented and by interviews only a feeling for these matters could be retrieved, but not a full picture.

12.2 Lessons learned from the cases

Knowing all strengths and weaknesses of the used research approach, conclusions can be drawn. One of the objectives in this research was to arrive at practical recommendations to drinking water companies on how to better deal with uncertainties in their planning processes. This was done by confronting theoretical notions from the descriptive and normative frameworks in chapters 4 and 5 with practical examples of how uncertainty was dealt with.
The conclusions have been divided into three parts. The first part concerns the leaving out of elements from the analysis. Questions that will be addressed are: How to go about leaving out elements? and; What are the consequences of leaving out elements? The second part concerns the making of assumptions: How to make assumptions explicit and what are the most difficult elements to make assumptions about? The third part is action oriented: How can a pro-active approach towards dealing with uncertainty be given shape? Finally some more general conclusions about dealing with uncertainty in drinking water projects will be made.
In combination with the practical conclusions that can be drawn from the case studies, the normative framework that was described in chapter 5 was translated into more practical recommendations. These guiding principles of 'good practice' in dealing with uncertainty are written throughout the text in italics.

12.2.1 The inclusion or exclusion of elements from the analysis

Excluding elements from the analysis or the decisions can have major consequences for the impact of future surprises and the extent to which a company is prepared for changes. By excluding external influences from the analysis an opportunity is missed to investigate how certain tactics will perform when these external influences turn out differently than expected, also when they were excluded for the reason that it was difficult to assess the possible impact of such an external variable.
The exclusion of external influences that are difficult or impossible to quantify can be appreciated in the light of a desire to make decisions on the basis of hard facts. This creates a misleading sense of security, however, because also less quantifiable external influences can have large consequences for the functioning of a system. An example of something that is hard to predict was given in the evaluation workshop. It was mentioned that in Amsterdam the use of drinking water by households of Dutch origin and that of households of foreign origin differs 30 to 40 liter per day. In Amsterdam a lot of houses do not have a water meter. The impact of installation of water meters on the water use of the mentioned households is difficult to make, but not considering any impact or assuming the same impact on both types of households is to be considered unwise.

Finding out which external elements were excluded implicitly can be done by studying those elements that were included in the analysis and comparing them to a list of elements that ideally are at least considered in a drinking water planning and decision-making process. In chapter 6, to this end the SEPTEMBER list was introduced. This list identifies five directions in which important external influences can be found. They are nature, society, politics, economy and technology. All the categories contain factors that potentially critically influence the infrastructure performance. All categories of external influences thus should be taken into account in order to uncover the potentially critical external influences.
Natural forces did not play a significant role in the cases that were studied. This does not mean that natural forces should be forgotten in planning processes. Nature can be the cause of very unpleasant events with or without long term effects. A thunderstorm, for instance can

have large consequences. September 24 2001 lightning struck both water winning stations of WRK, which are 80 kilometers apart! This event endangered the water supply in the whole Province of Noord-Holland. Luckily it had no permanent effects, operations were back to normal at 4 October (Cors et al., 2002).
Not only gradually changing social influences, as were identified in the cases, are important. Also social events have to be reckoned with in planning processes. Luckily no disastrous social events, like terrorist attacks happened in the four cases that were studied, but this is a point that needs not to be forgotten in planning processes. Only then, opportunities are not lost and everything has been done to prevent unnecessary losses.
Economic developments are not mentioned in any of the cases as being an external factor of critical influence to a decision, but it can potentially have large implications and can have sudden impacts. An example of the influence of economical external influences can be found in the effects of the oil-crises in the early 1970s which had a large influence on for instance the water sales of WBE. WBE delivers water to many large users in the Rotterdam area, among which are many petrochemical factories. In 2001 they sold 60.5% of their total amount of water to households, 6% to middle small users, and 33.5% to large users, including bulk supply to other companies (VEWIN, 2002). At the time of the oil crisis, the petrochemical industry needed much less steam in their production processes. This left WBE with a large amount of water for which there was no demand market (van den Noort and Blauw, 2000). This example illustrates that it can be wise to explicitly consider economic changes when making decisions.
The previous example also indicates a dependence of drinking water companies on the type of their clientele. When their clients are mostly households the drinking water companies are pretty certain of the demand for drinking water. The demand for drinking water by households is largely independent of the economical tide or other external influences, since they have no other alternatives. When the clients are others than households, for instance industries and farmers, the demand rates are not that certain, because they have alternative sources of water available, because they have the opportunity to save water to save money, or because their reason to demand water can come to an end. This can be shown with an example from the PIM case. Even though this had only a temporary effect, the pig- plague in the late 1990's caused a drop in the demand for drinking water by farmers.

The exclusion of tactics in a study may introduce future surprises. There will always be people that question the decision that was made for the reason that some alternatives did not get a fair chance because of questionable boundary conditions. When their voice becomes stronger the whole decision may be challenged even when preparations for the implementation of a certain tactic are well under way.
This leads to investments in tactics that may not get implemented, which can be considered to be a loss. On the other hand by investing in tactics that may not get implemented options are kept open, which can be considered to be a benefit (see chapter five). Which is better will depend on the situation. In the PIM and OEDI cases this protest about the tactic that was chosen came from within the drinking water company itself. They were not happy with the choice that was forced on them politically. This makes such decisions very hard or even impossible to enforce.

The outcomes of interest that usually are reflected in a multi-criteria analysis are, understandably, aimed at the functioning of the infrastructure. Examples are the capacity of the infrastructure, the quality of the delivered water, the reliability of the infrastructure, and the time until a new infrastructure part can be used. This is a logical consequence of the fact that these criteria represent the core objectives of the drinking water company. Criteria that reflect future interests are often lacking. This is a pity since this means a missed opportunity to test whether a decision is 'future proof'. The cause for this is that these kind of criteria are difficult to make measurable in a quantitative sense. But: also qualitative information about a tactic can be included in the consideration of that tactic! Tactics can for instance be ranked by experts on an ordinal scale. Even when for instance flexibility of a tactic cannot be translated into monetary terms, this tactic can be scaled by experts on a scale with plusses and minuses, two minuses being inflexible, two plusses being very flexible. In this way tactics can be compared to each other on flexibility, without exact quantification.

No evidence could be found that system boundaries are made explicit in practice. They are only implicitly adjusted when changes occur in external influences or outcomes of interest or when more promising tactics become available. This is a logical consequence of the fact that system boundaries in the cases that were studied are a natural consequence of geological, historical and technological boundary conditions. All the cases started with a question that was more or less determined by the technological system as it was. Capacity and quality issues all relate to the technological system. This way of working has been used and evolved over more than hundred years, and proved to work quite well. This explains why system boundaries are not a subject of explicit consideration. However, in some cases the system was viewed very narrowly and the assumption was made that solutions could mainly be found in the own service area and by acting alone. This attitude excludes a number of possible other tactics, and when this is done without consideration this can be considered a loss. Therefore: system boundaries should not be chosen too narrowly and certainly not when this is done implicitly.

Guiding principles

1. All five categories of external influences should be studied in order to uncover the potentially critical ones.
2. *Include all potential critical external influences, also the ones of which not much is known.*
3. Use both qualitative and quantitative data.
4. *Include criteria in decision-making that reflect future interests.*
5. *Define your system boundaries broad enough and do it explicitly.*

12.2.2 Making prognoses and assumptions

In planning processes always assumptions are made, for instance about how demand for drinking water will develop or about the moment of implementation of new regulation. It is in the nature of assumptions that they are not certain to come true.
Assumptions are best handled when made explicit. Explicitness enables that assumptions are reckoned with in planning and decision-making. Also this enables deliberate monitoring activities. Making assumptions explicit is a form of knowledge management. It is the only way in which others will be able to know what assumptions are at the basis of decisions and it is a prerequisite for later evaluation if assumptions have become reality and what consequences they may have. Knowledge of assumptions that were made in the past can benefit long term learning processes and can support decisions to change past policy because then it is known whether the basis of decisions is still valid.
Adopting a structured way of looking for assumptions facilitates the making explicit of implicit assumptions. The trick is to identify those assumptions that are critical. These need to

be taken care of, for instance by monitoring their development and by building in options in a design that can be used in case an assumption turns out to be false.

Assumptions that are difficult to make are those about social or political external influences, as was shown in chapter 11. This conclusion was supported in the workshop that was organized to evaluate the overall case study results. Political and social developments are whimsical and difficult to foresee. An approach to taking such developments into account that was mentioned during the workshop was the following: why not make plans for all kinds of generic things that can happen on theme basis. Thus not all developments need to be foreseen and plans are ready for uncertain developments. An other approach can be a 'devils advocate' approach when decisions have been made. What can happen that would change the decision at hand? These approaches are considered to be better than totally leaving social and political developments out of the analysis.

Also, it is not always easy for drinking water companies to make estimations of future demand. Certainly because demand, to some extent, depends on decisions of other actors. Drinking water companies at one hand are expected to be able to meet demand right away, but at the other hand, they cannot be certain when demand is going to increase exactly, and by how much.

Assumptions about other stakeholders are especially tricky in this respect, because their behavior and actions are not under control of the drinking water company. The delay of the realization of the VINEX locations in OEDI is a good example. The assumption of realization within a certain period in time of these locations was presented to WMN, who at its turn had to plan for this.

When drinking water companies invest in extra capacity too early, they run the risk that these investments were not necessary. When they invest too late, they risk having shortages, which is not accepted in Dutch society. Drinking water companies will have to steer a middle course between these two extremes. The best approach is to think in terms of flexible solutions that can be built in modules or be laid down very fast and by making plans on forehand for both occurrences.

It is unwise to manipulate prognoses so that they fit to the preferred alternative. De Bruijn et al. (1996) did find evidence of the existence of such behavior, but no evidence of such behavior was found in the cases that were studied for this thesis. This behavior can be very unwise from the point of view of dealing with uncertainty. It can hide the uncertainty in the assumptions that are made, which makes rational decisions with respect to dealing with uncertainty very difficult. Falsification of estimations in the assumptions that are made explicit is a recipe for future disaster. When this is done for critical assumptions the whole base of the decisions that are made may be wrong. Thus making the functioning of the infrastructure very vulnerable for future changes which have not been considered in the decision-making phase.

Faring blind on economical projections of third parties carries the danger that the consequences of trend breaks are not fully appreciated in the decision making process. Thinking in terms of trend breaking events is not a common practice in the drinking water world. It can have its advantages, though, because it enables explicit judgment of tactics with respect to cost and benefits in changing circumstances and also sharpens the thinking in terms of options for the future. The first step in determining possible trend breaks is making assumptions explicit. Subsequently, the consequences of assumptions not coming true need to be evaluated on their effect on the prognoses.

Guiding principles

6. *Make critical assumptions explicit.*
7. *When making estimations don't forget to consider the possibility of the breaking of trends.*
8. *Political, social and economical external influences are the most likely to show sudden or unexpected changes. Make sure you are prepared for this.*
9. *Be fair in making prognoses: do not fool yourself.*

12.2.3 Taking action: re-activity versus pro-activity

It is necessary to be prepared for failing assumptions. For this thesis two ways of pro-actively preparing for future changes have been studied. These are monitoring in combination with signposts, and planning with options for the future. With a reactive approach towards changing circumstances, opportunities are missed to explicitly address potential changes in external influences on forehand. Thus missing the opportunity to incorporate options in tactics in a structured and conscious way.

To know whether critical assumptions are failing, monitoring activities should be carried out. Monitoring in combination with signposts makes timely action possible. Unfortunately, even when assumptions about external influences have been made explicit, it is not always possible to monitor them. Especially for critical events this is difficult. Examples from the case studies of such events are: the draw back of the river law permit in the PIM case, the detection of large Bentazon amounts in the river Rhine and the cryptosporidioses outbreak in the Jan Lagrand case. Some events, for instance from political origin, one can see coming. But even then, the outcome of political processes can be highly uncertain. In such cases monitoring will not guarantee timely solutions.

The explicit determination of signposts will not only indicate when action needs to be taken, but also serve as the memory of the company in case of changes of personnel. Signposts are only useful if they can be recognized in time to take appropriate action. The faster the pace in a given market, the less time there is to see what is coming and the less time there is to take action, even if you can see what is coming. Signposts should therefore be very specific and mark evident decision moments.

In the cases that were studied, no use of explicit signposts was found. This does not mean that they were not there at all, but it does mean that there was no explicit moment in a planning process that is used to identify them structurally and to monitor them.

In the evaluation workshop the ‘Plan, do, check, act’ cycle was mentioned. It was stated that the first two steps of this cycle are in order for drinking water companies, but that the ‘check’ and ‘act’ steps need some extra attention. This is in line with the case study results. Evaluation of decisions taken is considered to be useful, even though it is seldom done properly. Thinking in terms of monitoring, signposts, and evaluation activities could be of great help. Introducing such an approach would be totally new for drinking water companies since evaluation is not something that is done automatically.

Drinking water companies are not completely defenseless with respect to the effects of external events on the functioning of their system. The system can be made redundant. Drinking water companies are pretty well prepared for events that may cause disturbances in delivery. Design principles that are available to face such disturbances are for instance decentralization and spreading of essential parts of the infrastructure, such as water winning

points and pumping stations; doubling of infrastructure parts such as pipes and pumps, which is also useful with regard to maintenance; coupling of the network with neighboring drinking water companies; and using ring-type delivery water works, thus making sure that water supply can take place from two sides. All of these design principles are a standard part of the drinking water companies tactics.
The previous examples of making an infrastructure flexible and or redundant are all related to the day-to-day operations of the infrastructure. When one part fails, back-up options are available to maintain operations. Also, there are future oriented options that can be planned for or invested in that are more future oriented in the sense that they can be used to grab opportunities or avert threats that have to do with future events and trends that come on the path of drinking water companies. As was discussed in chapter 5 these kind of options can be divided in four categories: investing in time, flexibility, robustness or knowledge.
In some cases flexibility can be preferred over robustness. The implementation of robust tactics can have large implications for the later options that are available because it can limit the flexibility to react to future circumstances. In the PIM case the eventual decision to halt PIM was partly justified by the statement that building in modules was preferred to the large PIM. Also examples are available from other fields than the drinking water infrastructure that support this principle. For instance, the Deputy of State of Gelderland preferred sand winning on small locations over winning on large locations, which is potentially more efficient, because winning at large locations would complicate the reaction to new developments (ANP, 2001a). Another example: The water board Hunze en Aa in Groningen could gain fiscal profits by cross border leasing their water purification facilities. They decided not to do this because in this construction they were not allowed to pull down the facility for the coming 22 years. Otherwise they would not be able to use new technology, like purification with microbes (ANP, 2001b). This last example also indicates that there may be a profit in having options, since this company is willing to pay for options!

An advantage of a cautious approach towards the use of unproven technology is that a drinking water company is certain that it will get it's money's worth. On the other hand, when a drinking water company is too cautious it may choose for tactics that are already out-of-date by the time they are realized.

Drinking water companies seem to be prepared to pay a price for options, but they will not do this at all cost. When comparable tactics with and without options elements are available at equal cost the drinking water company will, no doubt, choose the tactic with the option elements. Not all drinking water companies, however, will be prepared to pay the same price for options as other companies. This is not surprising since it is very hard to compare potential future benefits to other more direct cost and benefits. Options, however, should be considered seriously, since options also reflect a value. This suggests that criteria should be formulated that reflect the value of an option, otherwise the tactics with option elements will run the risk not to be considered for instance for the reason of extra cost. Criteria that can be considered, and were used in some of the cases that were studied, were flexibility, the possibility to divide the implementation of a tactic in phases, and operational vulnerability. It appeared however, that these criteria are not used structurally and not always in the same context or fashion. Comparison between reports on even the same case therefore becomes hard. Drinking water companies need to develop a more structural approach in considering these criteria to use them to their full potential.

It is not very surprising that solutions for, for instance, capacity problems are mainly sought in technological measures. The infrastructure is completely in the hands of the drinking water companies and for technological solutions they don't need other parties in a structural sense. Tactics that are initially not always considered are, for instance, influencing other stakeholders through the use of information, deals, arrangements, pricing mechanisms, rewards, penalties, or by sharing or transferring of responsibility, for instance by cooperation with other drinking water companies.

Influencing demand is 'not done'. A drinking water company's mission is seen as to uninterruptedly provide sufficient drinking water, at sufficient pressure and of good and constant quality (see chapter 1). They feel that influencing demand would conflict with this mission. Water saving campaigns were supported from a environmental perspective, not to influence the needed capacity. For some consumers, like households, demand can hardly be influenced by the price that has to be paid for drinking water, for others it can be influenced (capacity and timing) by changing the price of drinking water. In the past, for instance, price changes have shown to influence demand of for instance farmers. For these customers it can be a tactic to try and influence demand. This idea was supported in the evaluating workshop.

Cooperation with other parties adds complexity and risks for the drinking water company caused by the dependence on these others. Nonetheless, it can also be beneficial, for instance in the form of cost reduction, sharing of risks or efficiency. The attitude of trying to be self sufficient that was seen in the studied cases could lead to sub-optimal solutions when evaluated from the point of view from cost to society as a whole. Therefore drinking water companies need to find the right balance in finding their own solutions and cooperating with others. Examples show that drinking water companies have started to realize this. Lately, more cooperation takes place than before. All of the drinking water companies that were studied have merged at present, cooperate or work closely together with other (neighboring) drinking water companies.

Guiding principles

10. *Monitor developments that can lead to the failing of critical assumptions, preferably in combination with the determination of signposts.*
11. *When choosing between tactics, remember that options can also reflect a value. Potential future benefits should be considered in a decision-making process.*

12.2.4 Limits of the normative framework

Drinking water companies have more interests than properly dealing with uncertainty. In the cases some observations were made that could not be explained or structured with the descriptive and normative framework that were developed for this research.

Dealing with uncertainty as one of the objectives

In the studied cases, dealing with uncertainties was not always completely successful, as can be concluded from the examples that were given in this chapter. Quite a few examples can be found of surprises that at least to some extent could have been foreseen or planned for.

Even when it is evident that all activities that have been identified contribute to successfully dealing with uncertainty about the future, it is not a given that companies will use them in practice. Projects usually serve more than one purpose, and dealing with long term uncertainty is only one concern or may even be the margin of the project. Not all goals can be served in every project and choices will have to be made. For instance, when a thorough analysis of all relevant external influences from a systems environment is made, this does not necessarily mean that also a monitoring campaign will be started. This decision often is not made by those who perform such analyses and over time the acknowledgement of the urge for specific monitoring themes can change, for instance because of a change in personnel of the drinking water company.

In any case the weighing of the factors time, money and effort will be very important. The success of dealing with uncertainty about the future is dependent on the extent to which uncertainty is accepted as given and consequences of unexpected events are put up with. Important is the vision on dealing with uncertainty of a companies management team. How much are they willing to spend to be better prepared (see 4.5)? A project will in practice hardly ever be a complete success or failure with respect to dealing with long term uncertainty.

The use of the analysis to justify decisions that were previously made

In the interpretation of multi-criteria analyses in the studied cases a tendency to favor the alternative that eventually was chosen can be observed. In this respect the theory of cognitive dissonance of Festinger needs to be mentioned (Janis and Mann, 1977). In a nutshell this theory states that after a decision is made, the attractiveness of the chosen alternative is magnified and the attractiveness of alternatives is diminished. Psychological experiments and field studies from different scientists show that after a commitment to a choice people are likely to avoid dissonant information and to evaluate dissonant communications in a biased way that facilitates the preference of the chosen alternative made (Janis and Mann, 1977). The same authors suggest that this phenomenon can even be observed before a decision is made.

When this behavior is taken to the extreme, this can have serious consequences. For instance when organizations fail to re-appraise alternatives because of the cognitive dissonance. The organization can get stuck with an inflexible piece of technology that does not even benefit the interests that it was originally chosen for. A recent Dutch example of the consequences of such behavior in organizations can be found in the Betuwe Route example. This plan for a new to built freight train route from Rotterdam to Germany was very disputed. National government was and still is unwilling to halt the project, and possible go-no go moments were not used to stop the project. The project is expected to make no profits, which was the original reason for the project, but is still being carried out. By setting explicit signposts beforehand disastrous consequences of such attitudes may be prevented.

Management of large projects

Abandonment of projects in the planning phase is a costly affair. It cannot be concluded that the abandonment of projects is caused by mismanagement or by bad luck. Conversely, projects that turn out well may have been well managed but they may also have been lucky (Lessard and Miller, 2000). Whether an abandonment of a project can be considered a failure can be debated (de Bruijn et al., 1996). It is true that much was spent, but a project still can have had positive impacts, like the reservations of space for future capacity expansion in the PIM project or the insight that a project is not necessary any longer and further spending can be prevented. Thus it can be argued that the halting of a project can be seen as acting meticulously. The Wetenschappelijke Raad voor het Regeringsbeleid (the Netherlands Scientific Counsel for Government Policy), however, is critical about positively accepting abandoned projects. Such projects, in their opinion, do not only lead to huge loss of capital, but also undermine the authority of government and harm the governmental ability to initiate and examine projects (WRR, 1994).

In this respect the theory of David Collingridge (1992) needs to be mentioned. He uses the term 'inflexible technology' to distinguish between large and small projects and to understand their success and failure. Indications of failure are: escalation of development cost, crossing

deadlines and failure to meet technological specifications. His lesson is that managers better keep their hands off from large projects, i.e. don't undertake them at all.
The people in the evaluation workshop agreed that small projects are potentially more flexible and better to oversee, but that sometimes large projects are needed to get ahead. It was mentioned that in the past large uncertain projects were undertaken of which now the fruits can be picked. Like for instance the Jan Lagrand purification facility. When no risks are taken drinking water purification can never be elevated to a next level. For each circumstance it needs to be decided whether a large or small project is best. The tendency to always have large projects, however, is no longer present.

12.3 Management of uncertainty: broadening the perspective
The 'good practices' that were discussed can be used in many different settings and circumstances. Since in this thesis only Dutch drinking water cases were studied these recommendations are probably useful in projects that are similar to the ones that were studied. Many of the recommendations, however, can be used more universally, for instance for other infrastructures and in other countries. Also, they can be useful for different types of projects of drinking water companies, for instance during the making of a strategic plan. For this thesis, however, no extensive research was done to explore this point.
The Dutch drinking water sector has some distinct characteristics that made it possible to research dealing with uncertainty in its basic form (see chapter 2): drinking water companies operate from a monopoly position. The sector is technology driven and even though some innovations have become available the last couple of years, the sector is not very dynamic. The infrastructure itself has a long life span and the demand on the capacity of the infrastructure can be predicted pretty well.
An infrastructure that for instance shows similarities with the drinking water works are for instance sewer systems (see for instance ten Heuvelhof et al., 1999, and 2001). The usefulness of systems diagrams was shown in a project about dealing with uncertainty in the decision-making about sewer systems (Meijer and Korving (2001), and Korving et al.(2001)).
Other infrastructures like electricity, telecom, roads and railroads also have some characteristics in common. Fact is however that these infrastructures need to be operated in a multi-actor, competitive setting and in a far more dynamic environment.
Many of the recommendations that were made in this thesis are universal. However, it needs to be said that the method that was used for the analysis in this thesis has a blind spot with respect to the multi-actor setting that characterizes other infrastructures. Technology stays important, but actions to counteract uncertainties that originate in this multi-actor setting will be more process based and political than in the drinking water sector.
Since in this thesis these dynamics could not be observed well, further research on the benefits of the recommendations in other countries, for other infrastructures, or for totally different kind of projects, even outside the infrastructure scope needs to be carried out to know if they are similar to those that have been identified for Dutch drinking water companies

As a starting point for such research, and as a final result of this thesis, some thoughts on management of uncertainty will be presented. It can be said that decision-makers have a number of choices that they consciously or unconsciously make with respect to dealing with uncertainty. Together these choices make up their management style with respect to uncertainty.
Based on the literature that was studied and the interviews that were held to shape this research, the following uncertainty related choices of managers were identified (see table 12.1).

Table 12.1. Uncertainty related choices for managers

1	**Ignoring** uncertainty	**Facing** uncertainty
2	Aiming for **flexibility**	Aiming for **robustness**
3	**Willing** to invest in dealing with uncertainty	**Unwilling** to invest in dealing with uncertainty
4	Focusing on **short term** solutions	Focusing on **long term** solutions
5	Acting **pro-actively** with respect to uncertainty	Acting **re-actively** with respect to uncertainty

For choices 2 and 5 one choice should not necessarily be preferred over the other from the point of view of properly dealing with uncertainty. With respect to choices 1, 3, and 4: it is better to face uncertainty, be willing to invest in dealing with uncertainty and focus on both short term and long term solutions (these statements and others like it are explained further in chapter 5).

How uncertainty is dealt with is dependant on the management style of a company's top-management. In analogy with some animals, four archetypes of uncertainty managers are identified, based on the previous described choices and personal observations in practice.

1. The hare: fast, movable, but vulnerable;
2. the cormorant: a jack of all trades: at land, in the water and in the air, but it is not a top-scorer;
3. the turtle: heavily protected, target minded, but slow; and
4. the ostrich: danger is spotted, but the head is put in the sand.

Each of these management styles has its own characteristics, opportunities and threats. Each style can be successful, but also can fail. The styles will in practice never occur in their pure form: they will interchange. A company needs to be aware of the fact which of the styles it is choosing to be able to fight its downsides. Table 12.2 shows some of the opportunities and threats of these management styles as they were observed in the case studies in this research and could be extracted from the interviews that were held.

Table 12.2. Opportunities and threats of four management styles for dealing with uncertainty

	Opportunities	Threats
The hare: fast, movable, but vulnerable	• Flexibility is dominant. • Surprises are used instead of fought. • Having options is very important.	• People in the drinking water company can get uncertainty tired when it is incorporated in procedures and the reason behind it fades. Monitoring activities that are essential to a flexible organization thereby can get to the background of attention. • The cost for the technology and aftercare can get very high. This is not always easy to explain.

The cormorant: a jack of all trades: at land, in the water and in the air, but it is not a top-scorer	• A balance is sought between cost and benefits of dealing with uncertainty. • Clear future opportunities and threats are acknowledged and managed. Less obvious opportunities and threats are not visited.	• Not all opportunities and threats are identified and used or managed. • No occurrence of heights in dealing with uncertainty: mainstream. • Cost can get very high when measures are not balanced and policy is not consistent.
The turtle: heavily protected, target minded, but slow	• Robustness is dominant. • Little chance of failure in that sense that threats have a hard time in harming the infrastructure.	• Chances are not seen. • Cost can get very high when threats are faced threefold. • Great risk to get behind the facts.
The ostrich: danger is spotted, but the head is put in the sand	• When things don't get to rough the hope is to survive without (further) investment. • Sometimes it is cheaper to let disasters occur and rebuilt after the fact then taking countermeasures.	• When threats become real no counter actions have been taken, leaving the drinking water company defenseless. This can be very costly.

Based on the case studies and the discussion about this subject in the workshop, it can be stated that most Dutch drinking water companies with respect to uncertainties up to present have had many characteristics of turtles. On some subjects some companies have the characteristics of cormorants, especially when the development of technological improvements is concerned. The other management styles are not clearly present. Because of the dynamics in other infrastructure we expect that the companies in these fields have different management styles to deal with uncertainty.

The implementation of the good practices will be easier in some companies than in others. It is dependent on the present way of working, the possible benefits that management expects from a different way of working and if investment is possible. The suggested approach only works if there is something to choose from and if there is a belief that uncertainties do matter.

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Appendix A Searching for assumptions in texts

Dewar (2002) suggests that assumptions can be found in documents by searching for the words will, must, can, should, might, could, and cannot. The word 'will' helps in both identifying assumptions about the future and about the organizations planned actions. 'Musts' also help in identifying underlying actions. Dewar mentions that this works best for electronic documents, since then the computer can do the searching. Beside this method of searching for assumptions, Dewar (2002) also mentions several other methods of searching for assumptions. It can be said that looking for ‘wills’ and ‘musts’ is a fairly easy, cheap and fast way of looking for assumptions compared to some of the other methods, but documentation is necessary and it thus can only be done when the planning has been finished to a great extent. Because no evidence was found in all cases that were studied of systematic ways of looking for uncertainty (chapter 11) this method was used to illuminate the potential benefits that such a method may have, but also to investigate the downsides of such method in the Dutch situation.

This way of looking for assumptions was used on the problem formulating and goal defining chapter of the EIA of OEDI (WMN, 1996), and in the Proposition on the execution of the Lek-duinplan (Duinwaterleiding van ‘s-Gravenhage, 1946). The words that were looked for in Dutch were: moeten, (must), kunnen (can), zullen, mogen (will), dienen (must), (be)hoeven (will need). More direct words that indicate expectations were also found like expect (verwachten), and foresee (voorzien). In the studied chapter of the EIA of OEDI, 31 sentences were found that contained these words. This is pretty much when it is considered that the studied chapter consists of only 7 pages A4! In the Lek-duinplan proposition, 114 sentences were found in 29 pages long document.

To know which assumptions are behind the wills and musts, it is necessary to interpret the statements that are made in the sentence, which is almost impossible to do without the inside information that can be provided by people that were responsible for the decisions made in a project or involved in the writing of the document that was studied.

The assumptions that can be uncovered can be future oriented. For instance: ‘The demand for drinking water <u>will</u> increase with 6 Mm^3’. They can also be action oriented. For instance: ‘Existing groundwater winning <u>must</u> be reduced’. The assumptions can either be about things that can almost be considered to be facts, like ‘By saving on the number and size of the works money <u>can</u> be saved’. But they can also point towards critical assumptions that do not need to come true and are potentially important to the functioning of the infrastructure as it results from the plan that was made, like: ‘The wasting of water <u>can</u> be prevented in future, for there were beneficial experiences with water meter tariffs’. Based on this assumption estimations about the future water use of household were made by DZH in the 1940’s. Water meters, however, showed to have no lasting effect, and the water use rose significantly. Obviously not all ‘wills’ and ‘musts’ that can be found in a document point towards assumptions about the project that is described. For instance some of them will be used to give direction to the reader of the document with sentences like: ‘Different alternatives <u>will</u> be explained below’.

One should keep in mind that behind every sentence with ‘will’ or ‘must’, more than one assumption can be found and that opinions can be divided about which assumptions these are. For instance in the sentence: ‘With respect to the autonomous development it is expected that existing water winning permits <u>will</u> be fully used and that in addition new permits <u>will</u> be applied for to be able to meet the increasing demand for water’. In this sentence at least three assumptions can be found: 1) Existing water winning permit will be used to the full; 2) New permits will be applied for; 3) Water demand will rise.

It turned out that this way of looking for assumptions works pretty well in Dutch as it does in English with the connotation that in Dutch it is not as fool-proof as in English, since Dutch does not necessarily need the words will or must to indicate an assumption about how something will be done or happen in the future, and that words like can and will in Dutch have conjugations (for instance, can: kan-kunnen, will: zal-zullen) that are not present in English. Therefore the method is not as thorough and takes more time for a Dutch text than it does for the similar text in English.

Appendix B Participants to the workshop and interviewees

Participants to the workshop 'dealing with uncertainty', February 9th 2004

Mw. A. Diepeveen	Waterleiding Maatschappij Drente
Dhr. F. van Zeil	Waterbedrijf Europoort
Mw. Freriksen	VEWIN
Dhr. L. Rosenthal	PWN
Dhr. W. Koerselman	KIWA
Mw. C. Mesters	KIWA
Dhr. R. Wisse	Delta
Dhr. G. Terpstra	WLB
Mw. M. Meijer	TU Delft
Dhr. W. Thissen	TU Delft (chairman)
Dhr. J. Knigge	TU Delft (GDR driver)

Interviewees

Case related interviews

PIM

Dhr. Philips	Brabant Water
Dhr. Van der Wens	Brabant water
Dhr. Meerman	Provincie Noord-Brabant

Lek-duin/ Maas-duin

Dhr. Rop	Duinwaterbedrijf Zuid-Holland

Purification facility Jan Lagrand

Dhr. Kamp	PWN
Dhr. De Bruin	Witteveen en Bos

OEDI

Dhr. Den Hartog	Provincie Utrecht
Dhr. Lubbers	Hydron Midden-Nederland

General interviews

Dhr. Arpadzic	Waterbedrijf Europoort (Now: Evides)
Mw. Barm	Waterbedrijf Europoort (Now: Evides)
Dhr. Bronda	DHV
Dhr. Kalf	DHV
Dhr. Lavooy	Duinwaterbedrijf Zuid-Holland
Dhr. Huyboom	Duinwaterbedrijf Zuid-Holland
Dhr. Jonker	Duinwaterbedrijf Zuid-Holland
Dhr. Vreeburg	KIWA
Mw. Van den Boomen	KIWA
Dhr. Langenacker	Flevolandse Drinkwatermaatschappij (Now: Hydron Flevoland)

Samenvatting (Dutch summary)

Het vervlechten van onzekerheidsanalyse en besluitvorming over drinkwaterinfrastructuur

Machtelt Meijer

Infrastructuur die is ontworpen om heel lang te functioneren is erg kwetsbaar voor veranderingen die op lange termijn plaatsvinden. Dergelijke veranderingen kunnen het functioneren van de infrastructuur beïnvloeden. Daarom is het heel belangrijk om vanaf het begin van planningsprocessen van infrastructuur rekening te houden met onzekerheden.

Dit proefschrift is gericht op drinkwaterinfrastructuur. Dit type infrastructuur wordt gekarakteriseerd door een lange levensduur. Veranderingen in het aanbod van bronnen (bijvoorbeeld water, energie, ruimte om ondergrondse netwerken aan te leggen), technologie en vraag naar het eindproduct zijn te verwachten, maar zijn moeilijk te voorspellen. Dergelijke veranderingen kunnen tot hoge kosten voor de maatschappij leiden als deze leiden tot het falen van het systeem of voortijdige afschrijving van bestaande infrastructuur.

Het belangrijkste doel van het onderzoek was het beantwoorden van de volgende vraag:

> *Kan het identificeren van en het omgaan met onzekerheden tijdens het planningsproces voor de Nederlandse drinkwaterinfrastructuur verbeterd worden? En zo ja, hoe?*

Om deze vraag te beantwoorden werd eerst een literatuur onderzoek uitgevoerd. Deze werd als basis gebruikt om een beschrijvend en een normatief raamwerk te ontwikkelen om case studies mee te kunnen analyseren. Deze raamwerken zijn vervolgens gebruikt om vier cases ex-post te analyseren. Ten slotte zijn de resultaten in een workshop besproken met een aantal mensen uit het drinkwater werkveld.

Het beschrijvende raamwerk is gebaseerd op een aanpak waarin een systeem wordt beschreven in samenhang met de invloeden op dat systeem. Deze invloeden bestaan uit externe variabelen die niet door een besluitvormer kunnen worden beïnvloed en uit de maatregelen die een besluitvormer kan inzetten. Het effect van beide typen invloeden op het systeem kan geobserveerd worden in veranderingen in de systeemuitkomsten die van belang zijn voor de besluitvormer.

Het normatieve raamwerk is ontwikkeld om het succes van het omgaan met onzekerheid van drinkwaterbedrijven te kunnen evalueren. Het raamwerk is gebaseerd op een causale opeenvolging van acties in een planningsproces die zou moeten leiden tot succes in het omgaan met onzekerheden.
Het bleek onmogelijk te zijn om het succes van het omgaan met onzekerheden direct te meten. Dit zou alleen kunnen door veel meer cases en veel langere periodes te analyseren. Daarom is ervoor gekozen om indicatoren voor succes te gebruiken als benadering voor het overall succesvol omgaan met onzekerheden door drinkwaterbedrijven. Voor elke causale actie werd een indicator voor het succesvol uitvoeren van deze stap geïdentificeerd. Het idee hierachter was dat als elke stap goed is uitgevoerd het succesvol omgaan met onzekerheden daar een afgeleide van is. De indicators voor het succesvol omgaan met onzekerheden waren:

- De relevantie en de consistentie van de systeemgrenzen en de relaties die meegenomen zijn;

- De rijkdom aan inputs en outputs die meegenomen zijn;
- De explicietheid van de aannames die zijn gedaan;
- De aanwezigheid van signposts (dit zijn gebeurtenissen of drempelwaarden die de verandering in de kwetsbaarheid van een aanname aangeven), een back-up plan en het bewustzijn van de relatie tussen de signposts en de aannames;
- De rijkdom, compleetheid van verkenning en de aanwezigheid van opties.

Vier cases zijn achteraf bestudeerd. Drie hiervan waren meer recent, één vond plaats in een verder verleden. De vier cases die zijn bestudeerd zijn:

4. Het Project Infiltratie Maaskant (PIM) 1972-2000, van Waterleidingbedrijf Oost-Brabant (WOB). Dit project werd gestart door het drinkwaterbedrijf om rivierwater uit de Maas en de Waal te kunnen gebruiken als bron voor drinkwater in plaats van grondwater.
5. Het Oever-Diepinfiltratie project (OEDI) 1972-2000, van Waterleidingbedrijf Midden Nederland (WMN). Dit project was bedoeld om het winnen en zuiveren van water uit het Amsterdam-Rijnkanaal mogelijk te maken.
6. Het plannen van drinkwaterzuiveringsinstallatie Jan Lagrand 1973-1999, van PWN, het drinkwaterbedrijf van het grootste deel van Noord-Holland. In dit project werd een grootschalige membraan zuiveringsinstallatie gerealiseerd om zuiveringscapaciteit te vergroten en zachter drinkwater te kunnen leveren.

4) Het Lek-duin- en het Maas-duin project 1874-1996, van DZH (Duinwaterbedrijf Zuid-Holland). Deze projecten werden ondernomen om water uit de rivieren Lek en Maas naar de duinen bij Den Haag te transporteren. Hier werd het op een natuurlijke manier verder gezuiverd met duininfiltratie. Besluitvorming en planning van 1939 tot 1965 werden bestudeerd.

De belangrijkste conclusie uit de case studies was dat drinkwaterbedrijven erg alert zijn op onzekerheden en dat er veel actie wordt ondernomen om er mee om te gaan. Er kunnen echter enkele suggesties worden gedaan om de analyse van onzekerheden en het er mee omgaan te verbeteren.

Ten eerste lieten de case studies zien dat niet alle belangrijke externe invloeden even veel aandacht krijgen. Politieke, maatschappelijke en technologische invloeden bleken het belangrijkst te zijn in de cases die werden bestudeerd. Politieke en maatschappelijke invloeden werden ook het moeilijkst gevonden om mee om te gaan.

Ten tweede, sommige externe invloeden werden herkend als belangrijk, maar werden niet in de analyse meegenomen omdat er niet genoeg over bekend was. Het succes van waterbesparende apparaten bleek bijvoorbeeld heel belangrijk te zijn. Als deze invloed in meer detail in de analyse was meegenomen zouden wellicht andere beslissingen zijn genomen.

Ten derde, in de cases werden aannames meer expliciet gemaakt nadat gebleken was dat ze niet op gingen. Als dit op voorhand al was gebeurd zou het misschien mogelijk zijn geweest om sneller een besluit te nemen over het veranderen van het beleid.

Wat de toekomst brengt is onzeker. Drinkwaterbedrijven laten hun gedachten daarom gaan over toekomstige mogelijkheden in hun besluitvorming. Signposts spelen echter geen belangrijke rol in het besluitvormingsproces.

Membraan technologie heeft een verschuiving mogelijk gemaakt van robuuste naar meer flexibele oplossingen. Toch blijft het in de praktijk moeilijk om investeringen in flexibele of robuuste elementen in een ontwerp te verdedigen, omdat het moeilijk is om toekomstige baten te kwantificeren.

Het onderzoek heeft geleid tot elf richtlijnen. De zeven belangrijkste worden hier uiteengezet. De principes zijn gebaseerd op de literatuur, maar ook op het bewijs dat deze in de praktijk belangrijk blijken te zijn en dat drinkwater experts deze als belangrijk hebben aangewezen:

8. *Bestudeer alle vijf categorieën externe invloeden (maatschappij, economie, politiek, technologie, milieu) om te potentieel belangrijke invloeden te kunnen ontdekken;.*
9. *Gebruik zowel kwalitatieve als kwantitatieve gegevens*. Ook kwalitatieve gegevens kunnen gebruikt worden om beslissingen op te baseren, bijvoorbeeld in een Ádvocaat van de duivel' aanpak. Anders worden in de besluitvorming belangrijke zaken wellicht over het hoofd gezien.
10. *Definieer je systeemgrenzen breed genoeg en maak deze expliciet.* Op deze manier kan men zeker weten dat alle mogelijk oplossingen meegenomen worden in de besluitvorming en niet over het hoofd worden gezien. In het OEDI project werd er uiteindelijk voor gekozen om water van een aangrenzend waterbedrijf te kopen. Als de systeemgrenzen te smal waren gekozen zou er misschien alleen in de eigen regio naar oplossingen zijn gezocht.
11. *Maak belangrijke aannames expliciet.* Het is belangrijk om te weten welke aannames zijn gedaan en welke aannames de besluitvorming zouden hebben beïnvloed als deze anders zouden zijn geweest.
12. *Vergeet niet naar trendbreuken te kijken als je schattingen maakt.* Zelfs als een trend altijd hetzelfde is geweest zou je moeten onderzoeken of dit zo blijft. De verandering van de trend van alsmaar stijgende watervraag naar stagnatie en zelfs achteruitgang van de vraag laat zien dat niets in dit opzicht zeker is.
13. *Monitor ontwikkelingen die tot het falen van belangrijke aannames kunnen leiden, het liefst in combinatie met het vaststellen van signposts.* In de case studies bleek dat de drinkwatervraag goed werd gemonitord. Het monitoren van andere belangrijke invloeden kreeg veel minder aandacht. In combinatie met een signpost kan monitoren een belangrijke bijdrage leveren aan het vaststellen van het moment waarop besluiten moeten worden herzien.
14. *Onthoud bij het kiezen tussen maatregelen dat opties ook een waarde vertegenwoordigen. Mogelijke toekomstige baten moeten in een besluitvormingsproces meegenomen worden.* Het is verleidelijk om maatregelen te waarderen op hun waarde voor het heden. Mogelijke toekomstige kosten en baten zouden echter ook meegenomen moeten worden.

Het implementeren van deze richtlijnen zal in sommige bedrijven makkelijker zijn dan in andere. Het is afhankelijk van de manier waarop gewerkt wordt, de voordelen die het management verwacht van een andere manier van werken en de mate waarin investeringen mogelijk zijn. De gesuggereerde aanpak werkt alleen als er keuze mogelijkheden zijn en men gelooft dat onzekerheden belangrijk zijn.

Curriculum vitae

Machtelt Meijer (1975) studied Systems Engineering, Policy Analysis and Management at the Delft University of Technology. She graduated in 1998 on the subject of interactive planning in regional water management. Hereafter she joined the policy analysis section of the faculty of Technology, Policy and Management to perform a PhD research on dealing with uncertainty in the drinking water planning process.
In 2003 she became a project leader for Rijkswaterstaat on the subject of 'Sustainable Building'.
Since 2006 she works as a policy advisor at the Ministry of Housing, Spatial Planning and the Environment in the field of 'Sustainable mobility'. Her main activities concern the reduction of noise and air pollution caused by several modes of transportation.