Diss. ETH No. 13992

Stakeholder analysis in water supply systems

A dissertation submitted to the
SWISS FEDERAL INSTITUTE OF TECHNOLOGY
ZÜRICH

for the degree of
DOCTOR OF TECHNICAL SCIENCES

presented by

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Zürich, 2001

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It is not because change is difficult that we shy away from tackling it.
Change is difficult because we shy away from tackling it.
(Lucius Annaeus Seneca, 4 BC – 65 AD)

Acknowledgements

In the first place I would like to thank my advisors: Willi Gujer for giving me the opportunity to write this dissertation, for his guiding inputs to the project, his scientific enthusiasm and his ability to make time available whenever needed. Tove A. Larsen for demonstrating to me the art of listening carefully and then giving a specific answer or asking a precise question. Claudia Pahl-Wostl for introducing me to the world of socio-economic modeling, the related scientific community as well as integrating me in her group. Thomas E. Downing for reviewing this dissertation and acting as my co-examiner.

I am also most grateful to my project partners in industry for their support and confidence as well as the many open-minded personal discussions I was able to have with them: special thanks go to H.-P. Klein, U. Bosshard, A. Kilchmann, F. Geering, U. Kamm, K. Lüchinger, P. Giacasso, U. Manser, H. Scheidegger, and Th. Wagner. They introduced me to the problems of the real world and opened many doors for me.

I am further indebted to Jan Burse, whose support in designing and implementing the computer model, providing model components and developing my programming skills was most valuable. Similarly, I thank Gérard Mohler, who introduced me to the many secrets of UNIX and solved all my minor and major problems in this domain. I would also like to acknowledge the many crucial inputs from Matt Hare regarding the model and its application. Further, I wish to thank Irene Peters, Johannes Kottonau, Markus Boller and Jeanette Behringer for their inputs of and hints to relevant economic, technical and social aspects.

Furthermore, my father, Richard Michell, Matt Hare, Katrin Hügel and Anke Schäfer did a great job in reviewing parts of the manuscript and making it more easily understandable and readable. Thank you.

Within the framework of a diploma thesis, many students added to my knowledge by completing their own work: many thanks go to Daniel Melters, Stefan Schmon, Harald Tarnowski, Alexandra Hilber, and Davide Medugno.

I was fortunate in being able to work in an environment which included many really nice colleagues and friends at the engineering department. I shall particularly treasure the interactions with the other PhD students as well as the excursions, discussions and train rides in their company to Rümlang. Special thanks go to my office colleagues with whom I shared many hours of silent work, light-hearted laughter and serious discussions: Kai Udert, Michael Thomann, Irene Purtschert, Dani Wild and Katrin Hügel. My numerous jogging rounds at lunchtime gave me the active break I needed. My thanks go to all those at the various EAWAG departments who made them into social events.

Finally, I would like to thank my parents for their continuous support and encouragement.

Summary

A shift of focus is essential if water supply systems are to be optimized and further developed. Emphasis was traditionally placed predominantly on the technical aspects. However, the technical problems have now been largely solved: strongly fluctuating demand for water can be satisfied at any time by a high-quality service. Nevertheless, the water utilities must cope with increasing pressure from a public claiming a lack of efficiency. Why, for example, was capacity expanded in the last 25 years in spite of a decline in consumption? Technical reasons alone cannot explain such phenomena. The interests, characteristic behavior and factual constraints of the stakeholders involved must also be taken into account and the focus broadened to include such aspects.

Furthermore, utilities face an increasing danger of becoming insufficiently flexible to anticipate existing and new challenges. Whereas they developed under stable and predictable conditions in the past, they are now exposed to a more dynamic and uncertain environment (e.g. uncertain consumption development, new technologies such as the local use of rainwater competing with the centralized supply network, strong liberalization pressures etc.). Although flexibility is required to cope with this development, the long life span of the infrastructure, existing regulations and the prevailing "supply-oriented" incentives given to various stakeholders impede adequate system management. The traditional means of ensuring the required flexibility – large infrastructures with built-in redundancy – are no longer suitable in view of the explicit need for overall efficiency. Existing engineering rules must be rethought in the light of these recent changes.

The objective of this research project was to contribute to the knowledge of the influence and effects of stakeholders on water supply systems. What are the prevailing interests, strategies of action and interactions among the relevant stakeholders? The project also aimed to point out existing risks of current stakeholder behavior and to identify possible ways of designing and operating water supply systems which increase flexibility and adaptability.

In order to address these goals, a specific methodology was developed on the basis of a combination of sociological and technical tools. It contains the following steps:

- Typical rules of behavior of the stakeholders are proposed by the facilitating knowledge engineer on the basis of the literature, interviews and observation. These rules are presented in an "if - then" format. For example: "If capacity reserve is less than 20%, then an expansion of capacity is planned".

- With the aid of domain knowledge obtained from the stakeholders involved in a participatory process, these rules are discussed, analyzed, changed and supplemented. This process results in a rule catalog which documents the characteristic goals, interests, strategies and rules of behavior.

- An agent-based computer model comprising these rules of behavior is subsequently de-

veloped. The validity of the model is checked by modeling the historical development of a real utility and comparing the model output (capacity, investments, water tariff, debt etc.) with the reality. A sensitivity analyses helps to check the relevance of individual parameters (part of rules).

- Once the model had been validated with data sets from a real utility, multiple-scenario testing was used to explore different management and engineering strategies, thus allowing ideas for developing flexible management and design schemes to be generated.

This methodology was tested in a case study. The interactions of relevant stakeholders, namely the utility managers, engineering firms, politicians, consumers and the state, were analyzed and quantified. This process resulted in an improved understanding of the incentives and constraints of the stakeholders and the decision-making rules which they applied. It also served to structure the discussion, to visualize the influence and behavior of the stakeholders and to stimulate their intuition and awareness of future developments.

Despite the complexity of water supply systems, the model – based on about 140 rules of stakeholder behavior - was able to replicate the general development of both capacity and cost-related variables. The sensitivity analysis performed indicated that no specific parameter of the behavioral rules applied by the engineers dominates the development of the infrastructure (e.g. 15 or 20% reserve). More importantly, the development of average consumption, especially consumption peaks, and the strategies applied (e.g. targeting a reserve or not), constitute the significant factors contributing to the development of the infrastructure.

The performance of three different strategies (sets of rules) was initially tested against general demand patterns. The strategies were then applied in retrospect to the observed development of consumption in the past. And thirdly, they were used to generate a selection of scenarios of the future development of the utility. The benefits and limitations of the strategies were visualized and became the subject of debate. It was shown that the traditional rules of engineering almost inevitably lead to large capacity reserves. This results in inefficient operation, higher costs and possibly to technical problems. It may also involve a risk of sanctions from consumers and politicians, thus limiting the utility's flexibility and freedom of action.

In view of these risks and the uncertainty of future developments, the strategic and operational flexibility of a utility may be enhanced by introducing demand-side management. Such a strategy emphasizes the active influencing and guidance of demand and focuses on water services rather than merely on the quantity of water provided to consumers. It may well lead to long-term benefits, and any short-term drawbacks are manageable.

If the design and supply concepts are to be adapted to the new risks and situation as described above (e.g. declining demand, financial focus, political skepticism, renewal of existing infrastructure), then the web of incentives must also be changed. Incentives influence the outcome of the planning process by setting the boundary conditions within which the stakeholders can optimize their response on the basis of their interests. Existing incentives still inhibit the utilities from improving their flexibility and performance. Incentives should be increasingly directed toward the services to be provided (e.g. produce clean dishes) and not toward the flow of water to be maximized (clean dishes with water). This change is indispensable for maintaining an efficient and affordable water supply system which is well accepted once again.

Zusammenfassung

Um Wasserversorgungssysteme optimieren und weiterentwickeln zu können, muss zunächst der Blickwinkel verbreitert werden. Denn traditionellerweise wurde fast ausschliesslich auf technischen Aspekten fokussiert. Heute sind die technischen Probleme aber weitgehend behoben: eine stark schwankende Wassernachfrage kann jederzeit befriedigt und dabei Lebensmittelqualität des Wassers garantiert werden. Trotzdem sind die Wasserversorgungen massiv unter Druck geraten, da ihnen mangelnde Effizienz vorgeworfen wird. Warum wurde zum Beispiel mancherorts die Lieferkapazität in den letzten 25 Jahren trotz sinkender Wassernachfrage erhöht? Solche Phänomene lassen sich mit technischen Argumenten allein nicht erklären. Offensichtlich spielen die nicht-technischen Aspekte eine wesentliche Rolle. Der Blickwinkel muss auf die Interessen, Anreize oder Sachzwänge der involvierten Akteure (Ingenieure, Politiker, Konsumenten, Staat etc.) erweitert werden.

Auch müssen die Wasserversorgungen vermehrt flexibel auf sich ändernde Umwelteinflüsse reagieren können (unsichere Verbrauchsentwicklung, konkurenzierende Regenwassernutzung, Liberalisierungsdruck etc.). Die traditionellen Massnahmen zur Erhöhung der Flexibilität – Redundanz im Leitungssystem und grosse Kapazitätsreserven – sind dazu aufgrund des allgemeinen Effizienzdrucks nicht mehr geeignet. Entsprechend müssen die Sichtweise geändert, die gängigen Ingenieurregeln hinterfragt und neue Versorgungskonzepte entwickelt werden.

Das Ziel dieses Forschungsprojektes ist, das Verhalten der Akteure und den daraus resultierenden Einfluss auf die Entwicklung der Wasserversorgung zu ergründen. Welches sind die vorherrschenden Interessen, Handlungsstrategien und Interaktionen der Akteure? Mögliche Defizite der heutigen Versorgungsstrategien sollen aufgezeigt und Massnahmen identifiziert werden, welche die Handlungsmöglichkeiten der Wasserversorgungen erhöhen.

Dazu wurde eine Methodik entwickelt, die auf der Verknüpfung von soziologischen und technischen Werkzeugen basiert. Sie beinhaltet die folgenden Schritte:

- Die typischen Verhaltensregeln der Akteure werden aufgrund von Beobachtungen, Literaturrecherchen und Interviews in Form von "wenn – dann" Sätzen postuliert. Zum Beispiel: "Wenn die Kapazitätsreserve weniger als 20% beträgt, dann wird eine Kapazitätsvergrösserung geplant".

- Diese Regeln werden in einem partizipativen Prozess mit den involvierten Akteuren diskutiert, analysiert, verändert und erweitert. In dem daraus entstandenen Regelkatalog sind die charakteristischen Ziele, Interessen, Strategien und Verhaltensregeln der Akteure dokumentiert.

- Ein agenten-basiertes Computermodell wird entwickelt, welches die eruierten Verhaltensregeln auf ein virtuelles Wasserversorgungssystem anwendet. Die Richtigkeit des Modells wird durch die Abbildung der historischen Entwicklung einer realen Wasserversorgung überprüft. Dabei wird die Entwicklung von technischen und finanziellen Variablen wie Kapazität, Alter der Leitungen, Investitionen, Preis etc. in Realität und Modell

verglichen. Eine Sensitivitätsanalyse hilft, die Relevanz von einzelnen Parametern (Bestandteile der Regeln) zu überprüfen.

- Durch die Simulation von alternativen Planungs- und Managementstrategien der Akteure wird untersucht, wie auf die Unsicherheiten, Risiken und Chancen der Zukunft am besten reagiert werden könnte.

Diese Methodik wurde auf eine städtische Wasserversorgung angewandt. Beschrieben wurden die Wasserversorgung, eine Ingenieurfirma, politische Vertreter, Konsumenten und Behörde (Staat). Dies führte zu einem verbesserten Verständnis der Ziele, Interessen, Sachzwänge und Handlungsstrategien der Akteure. Dabei ist der Gesamtprozess wichtiger als die Resultate der einzelnen Schritte. Er ermöglicht, die oft nicht explizit bewussten Entscheidungsregeln der Akteure zu strukturieren, diskutieren und visualisieren.

Trotz der Komplexität der abgebildeten Wasserversorgung konnte das Modell – basierend auf ca. 140 Verhaltensregeln – die generelle Entwicklung sowohl der technischen als auch der finanziellen Aspekte über die letzten 100 Jahre nachbilden. Die Sensitivitätsanalyse zeigte, dass für die Entwicklung der Infrastruktur nicht die einzelnen Parameter der Regeln entscheidend sind (z.B. 15 oder 20% Reserve), sondern die angewandten Ingenieurregeln selbst (z.B. wird eine Reserve angestrebt oder nicht) und die Entwicklung der Wasserverbrauchsspitzen.

Die Simulation von drei verschiedenen Strategien offenbarte deren Vor- und Nachteile, womit das Bewusstsein der Akteure für Chancen und Risiken der verschiedenen Handlungsoptionen geschärft wurde. So konnte die Simulation zeigen, dass das traditionelle Ingenieurkonzept, die Wassernachfrage unter allen Umständen zu befriedigen, fast zwangsläufig zu grossen Kapazitätsreserven führt. Dies wiederum erhöht die Kosten und kann betriebliche Schwierigkeiten verursachen. Schliesslich resultiert das Risiko von Sanktionen seitens KonsumentInnen und PolitikerInnen, was die Handlungsfreiheit erheblich einschränkt.

Einen Ausweg aus diesem Dilemma bieten Strategien wie das *"demand-side management"* (aktive Beeinflussung der Konsumenten). Dieses Konzept fokussiert nicht auf die Lieferung von möglichst viel Wasser (um z.B. Geschirr zu waschen), sondern auf das Erbringen einer Dienstleistung (z.B. sauberes Geschirr erzeugen). Damit bekommen die Anbieter mehr Möglichkeiten den Verbrauch zu beeinflussen, ohne dass es zu Einbussen für die VerbaucherInnen kommt. Das Konzept verspricht langfristige Vorteile, während kurzfristige Nachteile aufgefangen werden können. Entsprechend wird die schrittweise Einführung dieser Strategie empfohlen.

Wenn solche neuen Strategien für die Weiterentwicklung der Wasserversorgung eingeführt werden sollen, müssen auch die bestehenden Anreizsysteme geändert werden. Diese geben die Randbedingungen vor, innerhalb derer sich die Akteure aufgrund ihrer Interessen optimieren können. Die Anreize müssen so modifiziert werden, dass es sich für die Ingenieure lohnt, die Optimierung der Dienstleistung in den Vordergrund zu stellen und die Dimensionen von Infrastruktur und Wasserfluss zu minimieren. Diese Veränderung ist unabdingbar, wenn in Zukunft ein effizientes, bezahlbares und in der Bevölkerung wieder gut akzeptiertes Wasserversorgungssystem erhalten werden soll.

Contents

Chapter 1

Introduction

A methodology was developed in this research project with the aim of revealing the characteristic patterns of stakeholders' behavior in water supply systems. The interactions of a subset of stakeholders were then quantified in a case study on the basis of this methodology. This process led to an improved understanding of the decision-making rules applied by the stakeholders. An agent-based model comprising these rules of behavior was subsequently developed. Once the model was validated with data sets from a real utility, multiple-scenario testing was used to explore different strategies, thus allowing ideas for developing flexible management and design schemes to be generated. The following introductory chapter describes the background to and motivation for the study.

1.1 Phenomena observed in water supply systems

When the infrastructure of urban water supply systems was developed during the last century, problems of interaction between human water use and the natural water cycle were viewed predominantly from an engineering perspective. The solutions to challenges such as the provision of raw water and its purification, storage and distribution to consumers, were based on measures related to "technology". Whenever a new problem such as a water shortage arose, the demands of consumers were satisfied by applying even more technology (such as new waterworks). Today's water supply systems are the result of constant technical improvements over the last 150 years. These technical solutions successfully paved the way for good hygiene, convenience, industrial development and social welfare in today's industrialized societies. The importance of the systems put in place are not only apparent in the daily life of consumers. Their impacts are no less remarkable in financial terms. It is estimated that a quarter of the investments made in the past by an average Swiss municipality were directed to the water supply infrastructure. Another third of the investments flowed into urban drainage and waste water treatment. Consequently, the replacement value of the Swiss drinking water supply network is now about SFr. 50 billion (Lehmann, 1994).

As a result of these constant improvements, the technical knowledge of water supply systems is highly advanced (Grombach et al., 2000). It is well understood how to purify water to the highest standards, how to construct huge water mains and how to automate and regulate entire water-supply systems. However, it is often hard to understand why some technologies are implemented in preference to others or why policy decisions go one way rather than another. Such phenomena can be observed in Switzerland by comparing the country's water utilities. It would seem that the system in its entirety is still not understood to a satisfactory degree.

A phenomenon of initial interest is the existence of large reserve capacities, which can even be considered to represent over-capacities in some cases. During the last 25 years, the demand for water by consumers has constantly fallen as a result of reduced volumes of water use and water recycling by industry as well as more efficient household technology (SVGW, 1999). In spite of this clear trend, the existing capacity of the water supply network has not been generally adapted (down-sized) to the new pattern of demand. On the one hand, this situation may be due to the long life span of the infrastructure elements, which cannot be adapted in the short term. On the other hand, the formulation of new master plans or political guidelines is not observed, contrary to expectations. A related phenomenon is the current condition of large parts of the infrastructure. Many elements, especially water mains, are older than their expected life-span, resulting in frequent burst pipes (Kamm, 1993; Wieman, 1993). It thus seems that whereas it was possible in the past to construct infrastructures in time to meet the needs of a growing population, today the systems tend to be renewed or adapted too slowly.

A second observation relates to the efficiency of infrastructure usage. The ratio between the maximum (Qmax,max) and average (Qm,m) water flow through pipes is about 3 - 4 in urban areas. This means that the pipes are normally underutilized and transport only a quarter of what they could. Similarly, although waterworks are designed for peak loads, most of the time less than half of their capacity is used. It is remarkable that this inefficient use of a highly capital-intensive infrastructure seems to be widely accepted. Management concepts which try to influence consumption and aim to flatten its peaks are not put into practice consistently. However, they may lead to a more efficient use of the infrastructures in the long run.

A third, general observation is that the Swiss public is increasingly sensitive to the actions of water utilities. Water tariffs are discussed in the media nowadays and were even the reason for a recent official investigation (Preisüberwacher, 1998). By the same token, the ongoing construction of new infrastructures is questioned and may even be stopped (Wagner, 1999). Furthermore, utility managers are under increasing pressure to achieve an efficient delivery of the water service (cost effectiveness). Balancing system performance against cost is nothing new in principle, but public debate has focused dramatically on this issue in recent years (Duckworth and Clarson, 1997; Hertzler and Davies, 1997). On the one hand, the public wants services of ever higher quality at unchanged or lower cost. Liberalization or even privatization of the public utilities is advocated to provide an alternative to existing institutions as a general means of achieving such good but low-cost services (Haumann, 1999; Hames and Krüger, 1999). On the other hand, proposals to liberalize utilities have been unpredictably rejected in public referenda (NZZ, 2000). It is evident that it is more and more difficult to satisfy the demands of the various stakeholders. Utility managers lack the strategic or operational possibilities to react to these expectations, influences and sudden shifts of the public mood (Klein and Manser, 1998).

Overall, it seems that a surplus of technical knowledge is currently available in water supply engineering as against a dearth of cybernetic and behavioral knowledge. The utilities need a better understanding of this latter kind of knowledge. However, they lack the tools to discuss and understand the dynamics of the relevant systems more effectively.

1.2 Stakeholders

The argument is increasingly heard that good solutions to man-made problems require more than technologically perfect systems (Abbott, 1999; Beck, 1997; Larsen and Gujer, 1997; Jeffrey et al., 1997; Guy and Marvin, 1996b; Niemczynowicz, 1996; Geldof, 1995). It is claimed that in order to understand the reasons for the phenomena outlined above, the complexity of the systems involved needs to be better understood in its entirety. In particular, more knowledge is needed about the social dimensions of urban water management systems in general and water supply systems in particular.

The term "stakeholder" emerged at the end of the 1960s from the field of business management and has gained increasing recognition ever since. Stakeholders are people or organizations who are not necessarily shareholders in a company, but without whose support, influence or action, a firm would cease to exist (Mendelow, 1987; Patton, 1997). Stakeholders are all those who affect, and/or are affected by, the policies, decisions or actions of a system. They may be individuals, communities, social groups or organizations. The term thus includes policy makers, planners, design engineers, consumers, administrators and governments (Grimble and Chan, 1995).

The "stakeholder analysis" approach originated in the 1980s in response to the need for business management to deal with the increasingly complex social systems in which modern corporations must operate. In the beginning, the approach was primarily descriptive. Thus systems were described as constellations of cooperative or competing interests of their stakeholders. In recent years, new analytical techniques have been opened up by simulations with computer models. They provide a way of shifting the focus away from a system's output variables to its inputs.

A stakeholder analysis helps to reveal relevant relationships between stakeholders and their effects on the system (Schaltegger, 1999). It seems promising to examine the role of stakeholders in water supply systems with regard to the observed phenomena described in the previous section and the increasingly complex setting in which today's utilities must operate. Since the actions of these stakeholders guide the development of the system, it will certainly be interesting to analyze their various influences and effects. Also the World Bank – traditionally a rather conservative organization – acknowledges the importance of stakeholder influences and recently initiated a study to determine their impact on South Asia's water and sanitation sector (Worldbank, 2000). However, it is a new departure in the water supply setting to shift the viewpoint from the technical side of water supply systems to examining the social side of stakeholders and their behavior within the context of their goals, constraints, incentives and fears. This new research field has not been tackled in depth so far.

1.3 Objectives and project procedure

The objective of this research project is to contribute to the knowledge of the influence and effects of stakeholders on water supply systems. It also implies increasing the understanding of the interactions between the macroscopic dynamics of the system (e.g. observed capacity) and the microscopic interactions of its sub-systems (i.e. the stakeholders). The project finally aimed to point out existing risks of current stakeholder behavior and to identify possible ways of designing and operating water supply systems which increase flexibility and adaptability. New qualitative knowledge of good management concepts and engineering guidelines may then be found.

The project thus involves the following specific research tasks:

1. To develop an *appropriate methodology* aiming to analyze the actions and interactions of the stakeholders.

2. To provide a tool to *structure the discussion* of the relevance of stakeholder influences (among participants such as engineers, sociologists, economists and politicians).

3. To *specify the behavior* of stakeholders, their tasks, incentives and strategies. The effects of this behavior and of good engineering practice are to be highlighted.

4. To gain a *better understanding* of the observed phenomena and the reasons why the relevant systems have developed in a specific way.

5. To provide a tool to *simulate scenarios* of future developments as well as the effects of stakeholder behavior.

6. To *identify possible ways* of designing and operating water supply systems which increase flexibility and adaptability.

7. To *point out existing risks* in current stakeholder behavior and propose management strategies or engineering guidelines which promote increased the flexibility of the utilities.

8. To *advocate and redirect further research* by defining new research priorities in favor of more sustainable and flexible urban water supply systems.

The results derived from the completion of these specific research tasks are organized in the following way:

- Chapter 2 summarizes the analysis of the problem domain. It reviews existing knowledge as found in the literature as well as the current characteristics of water supply systems. Only those aspects of these systems are highlighted and explored which are directly related to the research tasks.

- Chapter 3 gives an overview of various approaches to an institutional analysis. Parts of these techniques are required in order to build an overall methodology for this research project.

- Chapter 4 describes the methodology used (task 1). It is elaborated specifically to match the objectives and provides the basis for developing the model of stakeholder interactions.

- Chapter 5 shows the results of a case study. The stakeholder interactions relating to the water utility of a Swiss city are modeled and their output is compared to the observed development of the utility. The sensitivity of the model output to the model parameters is also explored. The chapter covers tasks 2, 3 and 4.

- Chapter 6 explores different scenarios of stakeholder behavior. It provides the basis for assessing the advantages or limitations of certain interaction patterns and deals with tasks 5 and 6.

- Chapter 7 discusses the characteristics, advantages and limitations of the methodology used (chapter 4), the resulting model of the case study (chapter 5) and the scenario simulations (chapter 6). Chapter 7 finally addresses tasks 7 and 8. It reviews the advantages and limitations of current management and design strategies and introduces alternative guidelines. Specific measures are proposed.

- Chapter 8 concludes and gives suggestions for future research.

Chapter 2

Domain analysis

This chapter analyses the problem domain. It explores aspects of the water supply system which are relevant or related to the research tasks outlined in the previous chapter and cover the technical, social and economic spheres. The chapter concludes by summarizing the characteristics of the domain. These include the inert static infrastructure, the great influence of many stakeholders and the role of best practice. Certain conditions are then established for the continuation of this research.

2.1 Characteristics of water supply systems

2.1.1 Current status

The history and current status of Swiss water supply systems are well documented. A review of the available literature reveals country-specific textbooks (e.g. Gujer, 1999; Boller, 1999), handbooks (e.g. Grombach et al., 2000) and large amounts of statistical data aggregated by the professional water supply association(e.g. SVGW, 1999). Many publications can be found in the main Swiss professional journal, "Gas Wasser Abwasser" (e.g. Boller, 1998). Further information on the water supply is also available from international sources (e.g. Twort et al., 2000; Stephenson, 1998).

The current status of the Swiss water supply systems, with particular reference to the topic of this work, can be summarized as follows.

- *High public expectations.* The task assigned to utility managers by politicians and regulatory bodies is to provide a comprehensive water service to consumers at all times. In the first instance, this service has been achieved by continuously expanding the supply capacity. Secondly, redundancy has been built into the water distribution network to prevent system failure due to the outage of a single infrastructure element. As a result, nearly 100% of the population can turn on a faucet at any time (sink, shower, garden hose) and draw water at an adjustable temperature, of drinking water quality, at a reasonable pressure and for as long as they require (no quantity limits). This performance is impressive. However, the consumers are now used to such a comprehensive service. Public demand to maintain this high quality of water provision is potentially high (and not known exactly). A reduction of this service level (for whatever reason) would hardly be acceptable.

- *Local structure.* There are currently about 3,000 water supply utilities in Switzerland. While each of the five largest ones delivers water to more than 100,000 customers, the 1,200 smallest ones serve fewer then 500 customers each (Klein, 2000). The general structure is thus characterized by heterogeneity in terms of size and little cooperation between municipalities. In spite of the generally small scale of distribution, the five largest utilities (0.15% of the total) deliver 25% of the total water supply and thus represent important players.

There are no compelling reasons for the existing structure. On the one hand, more responsibility could be given to individual consumers, resulting in an even smaller organizational scale (e.g. consumers would be responsible for parts of reservoirs or pipes in their neighborhood). On the other hand, many municipal utilities could be merged to form larger, regional units. A country of similar size, namely the Netherlands, had only 28 public utilities in 1997, and the aim is to reduce this number to about ten (Achttienribbe, 1997). Although geographical conditions in Switzerland cannot be compared to those of the Netherlands, a similar system would be possible. In Switzerland too, recommendations have been proposed that several utilities should be merged in order to share the operations and know-how required to provide the water service. However, there are still no clear indications that these recommendations are being put into practice.

In Switzerland, almost all the utilities are public, being bound tightly to the local administration and to political decision-making procedures. There is no competition for the service to provide water to the consumers within the same supply area. To achieve such competition is a delicate matter. The tendency of private companies to maximize profits has to be balanced against the public-health aspect of water supply. Although different forms of liberalization (complete or partial) have emerged in neighboring countries, sufficient long-term experience is not yet available to obtain a clear picture of the performance of these types of organization. Both negative headlines (e.g. Tages Anzeiger, 2000) as well as positive reports have been documented (Guillet, 2000).

- *Water productivity potential.* The amount of water required depends greatly on the household sanitary technology used to transform the water received into various services (such as removal of faeces by toilet flushing, cleaning dishes by dish washers, operating cooling systems for appliances). In recent years, water-saving sanitary technology has been introduced onto the market and is also partly responsible for the general trend to decreasing consumption (SVGW, 1999). Several studies have been conducted which show that the technology is now available to reduce water usage even further - by up to 50% - without loss of service quality (based on the average Swiss consumption per head, Mönninghoff, 1993; Koenigs, 1995).

  In spite of this potential, scant efforts have been made to consistently improve the water productivity of household installations. One reason for this is the lack of any overall urgency to save water in most areas (Berdat, 1996; Michel and Kamm, 1996). The replenishment of water resources by rain far exceeds their use for drinking purposes. Furthermore, utilities have no incentive to promote water savings in times when average consumption is already decreasing. The introduction of more efficient household technology would compete against the existing system, which is based on a rather generous flow of water. That is why no consistent efforts are made to enhance water productivity even in drier regions.

  An additional problem associated with the low water productivity of the present system is that it inhibits the transfer of know-how to the "developing" countries. In these regions, scarcity of water and droughts will be a major threat in the coming decades. Many regions (e.g. parts of India, China and Africa) already suffer from a lack of water. This situation will become aggravated due to population growth and (potentially) climate change. The water-rich countries will also suffer from this situation as a result of immigration and water conflicts (e.g. Zehnder, 1997). Since the "developing" countries are trying to copy developments in the water-rich countries, they must find solutions to water scarcity problems without the aid of expensive and water-wasting technology. Innovative and water-saving supply concepts are urgently needed there. Unfortunately, water-rich countries still offer a bad example and are of little help in this global situation.

- *Predominantly technological solutions.* A relatively far-reaching segregation of the water supply system from the socio-economic environment has been observed. Technology provides a means of ensuring the required operational flexibility. Existing supply concepts scarcely consider the possibility to an active approach to influencing water use (Guy and Marvin, 1996a; Giacasso, 1998). Consumers have as much water available to them as they need at any time. As a result, they are not particularly aware, if at all, of key information such as the level of water tariffs (Schmon and Tarnowski, 1999). Other reasons also contribute to this situation. Firstly, 70% of Swiss consumers do not own their house or apartment. As tenants, they never see the water bill for the water services they use, but pay their water charges with their rent. Secondly, tariffs are still rather low (Preisüberwacher, 1998), also in an international context (OECD, 1999). A cup of coffee in a restaurant is more expensive than 1,000 liters of good quality water delivered directly to the consumer's apartment.

- *Lock-in tendency.* The existing infrastructure network (pipes, reservoirs, waterworks) is largely invisible. Most of its elements are placed underground, which is one of the main reasons for the high investments needed to build or replace them. No less than 80% of the expenditures of a utility are fixed costs related to the expensive infrastructure. In the next 25 to 50 years, about SFr. 13,000 need to be reinvested for each inhabitant, which represents a significant part of municipal expenditures. The infrastructure elements need to be designed for an operating life of more than 50 years. Since the whole system must be compatible, existing pipe elements influence the design of adjacent new elements. Innovation is blocked by the constraints of the existing system. As a result, the system cannot be changed and a lock-in effect occurs. Once built, the capital is spent, and this affects the development of nearby network elements (Edenhofer et al., 1997; Wieman, 1996; Geldof, 1995). It is consequently difficult for the utility management to change strategies and the direction of investments. There is little incentive for system innovation.

- *Subsidies.* One of the four official goals of the federal government is to promote public welfare (Swiss constitution, paragraph 2). In order to achieve this goal, a reliable and well-developed water supply system is required. In the past, the government accelerated the development of the infrastructure by paying subsidies. In addition, the public fire insurance institution had (and still has) an interest in a reliable water supply system (which is also used to provide water for fire fighting). It consequently contributes to the investments required. Although these payments cannot be called subsidies because they do not come from the public purse, they are nevertheless regarded as such for reasons of simplicity.

  In total, around 20% to 50% of gross investments have hitherto been paid through subsidies. This was also a means of influencing the quality and size of the infrastructure. Regional differences (financial situation, degree of development) could be balanced out by adjusting the level of the subsidies.

  The payment of subsidies is no longer encouraged. The renewal of existing infrastructures is not subsidized (or only to a small extent). As a result, the financial load on utilities due to the infrastructure will increase in the future. Less income is also available since connection charges (paid by consumers when having their house connected to the existing network) are reduced. The financial burden on the utilities is thus greater than it was in the past.

In conclusion, the water supply system is static, locally organized and based on a generous flow of water. Its infrastructure is interdependent, occupies most of the utilities' budget and generally inhibits innovation. Operational flexibility is achieved by means of large technical solutions. Political guidelines and the resulting management concepts are supply oriented and designed to meet all demands. Public expectations are high.

2.1.2 Recent dynamics

The characteristics of water supply systems must be put into the context of their environmental dynamics. In the last 10 to 15 years, the development of the socio-economic environment has increasingly challenged existing strategies. New demands on utilities have not only changed the constraints but also put new pressures on the supply network and its operation. (Fig. 2.1).

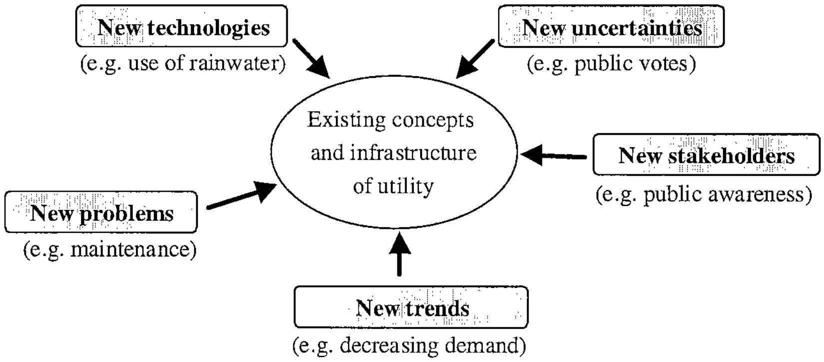

Figure 2.1: *Recent socio-economic developments challenge utilities.*

The introduction onto the market of *new technologies* such as the use of rainwater by consumers is seen as creating competition to the existing infrastructure (Michel and Kamm, 1996). The use of rainwater obviously results in a decrease of the water purchased from the utility. However, this is not expected to affect peak purchases, as in times of peak consumption – in dry periods – the rainwater tanks are likely to be empty. As a result, the size of the existing network could not be reduced. Nevertheless, less water would be sold and thus – at unchanged prices – less income generated. *New uncertainties* are also arising. The outcome of referenda on increasing tariffs or giving approval for construction investments is now more uncertain than ever (Wagner, 1999). *New stakeholders* (media, political parties, official controllers, private investors) take an increasing interest in the performance of utilities and must consequently be taken into account at various stages of the decision-making process (Duckworth and Clarson, 1997). *New trends* such as an overall decrease in consumption (in contrast to a generally increasing trend over the previous century) are challenging existing strategies which were developed in the past when the supply system was growing at a constant rate. And finally, *new problems* such as having to replace existing infrastructures while simultaneously operating them pose a further challenge for whose solution no long-term experience is available.

These recent developments in the socio-economic environment are even more significant when compared with the external influences exerted on utilities in the past. During the last century, water utilities were able to develop under fairly stable or at least foreseeable socio-economic conditions (Fig. 2.2). The utilities were the dominant player in the system setting. The effect of the system on natural resources and regulations was much greater than the other way around. Other stakeholders or influences had little effect (indicated in Fig. 2.2 by

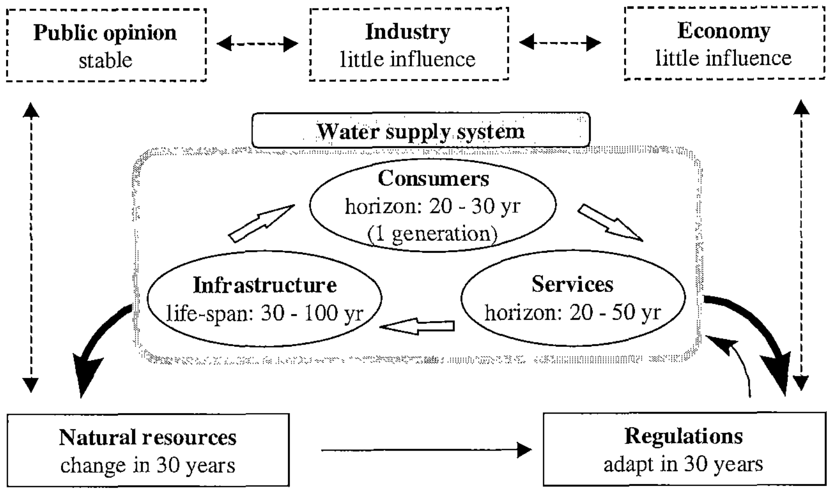

Figure 2.2: Influences on utilities during the past years.

dotted lines). The time scales for a change in government regulations, water resources or other influences were approximately of the same order as the planning horizon of the utility engineers who built the infrastructure or the horizon of the consumers (20 to 50 years).

In contrast, the situation experienced today is much more dynamic (Fig. 2.3). New influences, such as those shown in Fig. 2.1, stem from public opinion, industry and the state of the economy in general (e.g. recent recession). Furthermore, the time scales for change in these external influences range from about 5 to 10 years (estimation). The status of natural resources or regulations also changes more quickly today. Consumers tend to shorten their horizon (5 years) and the utility plans its services only 10 to 15 years ahead (e.g. finance plan). However, because the life-span of the infrastructure remains long, the utility is placed between two conflicting forces, i.e. the pressure from external influences on one side, and the inertia of the existing system on the other.

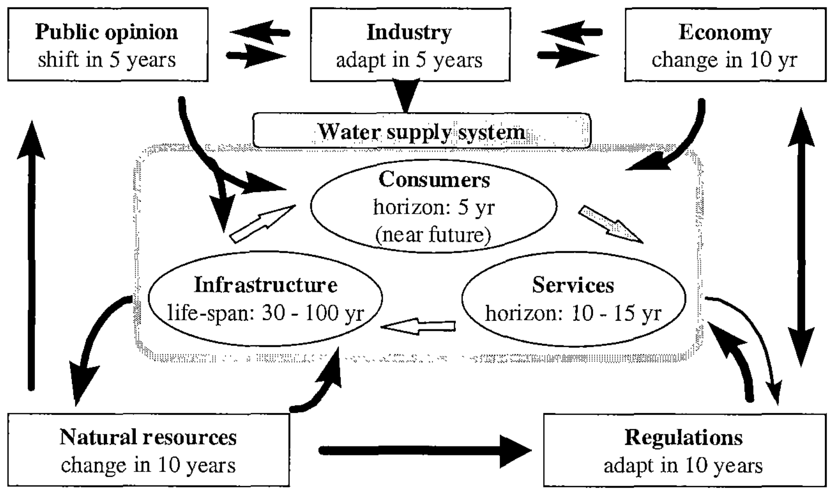

Figure 2.3: Influences on utilities in recent years.

The problems of time scales become visible when considering a scenario in which consumers use less water (Fig. 2.4). While costs are high due to depreciation, interest and the expensive replacement of ageing infrastructure elements, lower water consumption leads to rising water prices (per volume of water). The system cannot be adapted to this lower consumption in time to prevent an increase in price. The latter may lead some stakeholders to stimulate the market of water-saving technology (without support from the utility) or to draw political profit by focusing on prices. Consumers can be alerted to the price increase and can be motivated to save water in order to (potentially) save money. A further reduction of consumption would then result. This situation becomes aggravated if consumption is price-elastic. Studies in different European cities showed a relatively small price-elasticity of demand, namely -0.1 to -0.4 (OECD, 1999; Barbier and Cambon-Grau, 2000). However, these values cannot be transferred to any city, since the price structure and the way prices are charged, which are of crucial importance for elasticity, vary in different cities. Assuming price-elastic demand, a further price increase would result, which may in turn inhibit consumption etc. Finally, a drastic decrease in the amount of water used would even put the efficient functioning of the system in question (long residence times of water in the network with negative effects on its quality, degrading biofilms on unused sand filters in waterworks, damage to under-utilized pumps).

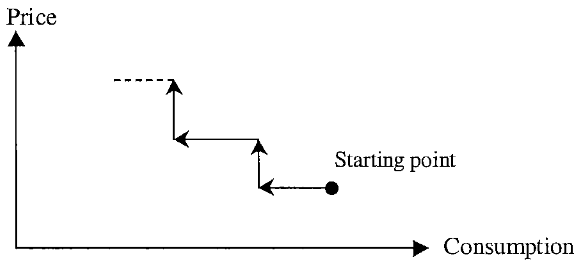

Figure 2.4: *Positive feedback cycle due to a scenario of rising water prices. An increase in the water price may initiates a decrease in consumption, which in turn leads to a further need to increase the price.*

Overall, recent dynamics of demand and the environment conflict with the existing water supply system, which is technically static. More stakeholders influence the system and create changing environments. The utility faces an increasing danger of being insufficiently flexible to anticipate current and new challenges (Klein and Manser, 1998).

2.1.3 Stakeholders involved

As already pointed out in chapter 1, *"stakeholders"* are people or organizations who have a stake – a vested interest – in the outcome of a certain issue[1]. On the one hand, stakeholders are people or organizations who are directly involved and who direct and influence the system in one way or another. Examples would be the design engineers or the responsible politicians. On the other hand, stakeholders are people who are affected by an issue. Examples are people who have to tolerate a fire hydrant in their garden, or whose land is expropriated because a reservoir needs to be built on their property.

Fig. 2.5 gives an overview of important stakeholders involved in Swiss water supply systems.

[1]The term *"actor"* is related to the term stakeholder and is often used in similar contexts. According to Webster's dictionary, an actor is, most generally, "one that takes part in any affair". The term actor is more specific than stakeholder. An actor pursues an action, is active with respect to the outcome of a certain issue. Actors are thus active stakeholders. All actors are stakeholders, but stakeholders are not necessarily actors (stakeholders may be passive). Consumers who receive water from a water supply system are stakeholders in that domain. However, they can only be considered actors if they are actively involved in the process (by complaining, being politically active etc.).

Legend:
I = Information, data, policy, proposal
M = Material (water, energy, particles, money)
B = Both (D and M)
y, d, h = Time scales year, day, hour
flux

		1 State	2 Politicians	3 Utility	4 Eng. company	5 Consumers	6 Profess. Assoc.	7 People, public	8 Farmers, agri.	9 Fire service	10 City planner	11 Media	12 Neighbors	13 Infrastructure	14 Drainage sys.	15 Sanitary inst.
Stakeholders	1 State, administration		I,y	B,d	I,y				I,y	I,y				I,y	I,y	I,y
	2 Politicians	I,y		I,d		I,y		I,y	I,y	I,y	I,y		I,y			
	3 Utility (public)	M,y	I,d		B,d	B,h	M,y		B,y	M,d		I,d	M,d	B,d		B,y
	4 Engineering companies	M,y	I,y	B,d			M,y							M,d	M,d	
	5 Consumers	M,y	I,d	B,h				I,d								M,y
	6 Professional association	M,y	I,d	I,d	I,y				I,y	I,y				I,y	I,y	M,y
	7 People, public opinion		I,d	I,y		I,d	I,y					I,d				
	8 Farmers, agriculture		I,y	M,y											M,d	
	9 Fire service			M,d	I,y		I,y				I,y					
	10 City planner		I,y	I,y	I,y		I,y									
	11 Media		I,d	I,d		I,d	I,d	I,d								
	12 Neighbor cities		I,d	I,y												
Domain objects	13 Infrastructure (pipes, etc.)			M,d		M,h				M,h					M,d	
	14 Drainage system		I,y	B,y												
	15 Sanitary installations			I,y		M,y									M,d	
Exogen. influenc.	16 Economic pressure	M,y	I,d	M,y	I,y	I,y										
	17 Resource availability		I,d	M,d					M,d			I,d				

Figure 2.5: *Stakeholders, domain objects, external influences and the links between them. Information is passed on (from rows to columns) either as information ("I"), material ("M") or both ("B"). Interactions are based on different time scales (y, d, h). A further model depiction of how stakeholders interact is given in Appendix A.*

- A first group of stakeholders promotes the system. They are also responsible for it: a) the *state (1)*, which determines many of the boundary conditions for public utilities [2]. They also decide on accounting modes, depreciation rates, and the level of subsidies available for expanding infrastructures; b) the executive and legislative arm of government, namely the *politicians (2)*, who are politically responsible for the (public) utility, approve decisions, inform the public and propose new initiatives; c) the *utility (3)*, which operates the network and is responsible for the provision of water services; d) the *engineering companies (4)*, who construct the infrastructure and are dependent on job orders; e) the *professional associations (6)*, who develop standards and guidelines and act as lobbying organizations; and f) the *urban planners (10)*, the main experts who forecast the future population and thus provide the basis for the future size of the system.

- A second group of stakeholders primarily benefits from the system: a) the *consumers (5)* (individuals, small businesses, industry) as the main recipients of all services, including the *fire service (9)*; b) the *farmers (8)*, who use water for irrigation purposes; c) the *neighboring cities (12)*, which may receive water to cover their own needs.

- A third group of stakeholders influences the system but does not bear any responsibility for it: a) the *farmers (8)* who may spoil drinking water resources by over-fertilizing land; b) *public opinion (7)*, which is driven by the population as a whole. They develop a specific mood which may inhibit or stimulate the development of the infrastructure; and c) the *media (11)* who may influence decisions in a subtle way.

Domain objects are objects which are part of water supply systems. Examples are waterworks, pipes, reservoirs, buildings, hydrants, sanitary installations in houses etc. External influences provide further constraints to the development.

[2] With respect to the water supply systems in Switzerland, the "state" refers to the "cantons". The cantons have overall supervisory responsibility for the appropriate implementation of water supply systems. Switzerland is divided into 23 cantons, which in turn are divided into approximately 3,000 municipalities.

The resulting interactions are based on different time scales (year, day, hour) and involve different types of content. They may consist either of "information" (data, policy, proposals etc., shown in Fig. 2.5 as "I"), or of various types of "material" (water, energy, particles, money etc., shown as "M"). Developments are influenced not only by stakeholders but also by domain objects (e.g. the infrastructure). Thus the fact that the life-span of pipes exceeds 50 years imposes significant restrictions on other stakeholders or domain objects. External influences such as economic pressure on the finances of individuals, the utility or the state as a whole also influence the system. For example, the flexibility of the utility is considerably affected if the economy is in recession as opposed to when it is booming. A further, different and detailed model depiction of the water supply system is given in Appendix A.

The interactions shown in Fig. 2.5 represent a typical situation prevailing in the Swiss water supply systems. However, they are not complete. In principle, all table fields could be filled with a particular influence. Moreover, every specific utility is influenced by additional stakeholders, domain objects or external sources according to the local situation.

The *fire service (9)* plays a special role. Especially in smaller localities (less than 3,000 inhabitants), the fire service determines the minimum capacity. Since the drinking water system must also serve as a water delivery system in case of a fire, minimum water volumes are reserved for this service. Hence this stakeholder exerts a great influence on the size of the distribution network and storage volumes in smaller supply systems.

Figure 2.5 shows only those interactions which are based on visible and clearly describable parameters: consumption data, policy information, flow of money or water etc. But interactions among stakeholders may include other informal elements such as lobbying (for or against something) and teaming (cooperative ventures with a common interest).

Feedback loops are also present in the system. Thus the utility influences politicians, who in turn have an effect on the utility. Because of such feedback loops, it is not easy to determine where the important links are located. The time scales give no clear indication either. Does a link which occurs on an annual basis have more impact than one which occurs daily? The importance of a single link cannot be quantified.

However, the table gives a clear indication as to whether a stakeholder has interactions to many or few other stakeholders (e.g. professional associations versus the media). Since no statements can be made about the importance of individual interactions, the best assumption is that the number of interactions indicates the importance of a stakeholder in the system. This would mean that the upper half of stakeholders is more influential than the lower half. These are also the stakeholders who are most directly related to water supply systems. The domain of engineering is in the center, targeting consumers and surrounded by politicians and the state.

From these considerations, three conclusions have been drawn with respect to the scope of further research. Firstly, only a selection of stakeholders will be further explored as a starting point: utilities, engineering firms, politicians, consumers and the state. Secondly, a large city must be selected as a source of further data in order to avoid the excessive influence of the fire service. And thirdly, the driving forces of the interactions must be investigated further.

2.2 Driving forces

The driving forces in the development of water supply systems can be divided into two categories (Fig. 2.6). Firstly, the influence summarized as "technical knowledge" resulting from the scientific and technical education of the engineers who design the system. Secondly, the influence of the "institutional rules" resulting from stakeholder interactions. Whereas the first influence is based on empirical data, the latter is more complex and requires further investigation.

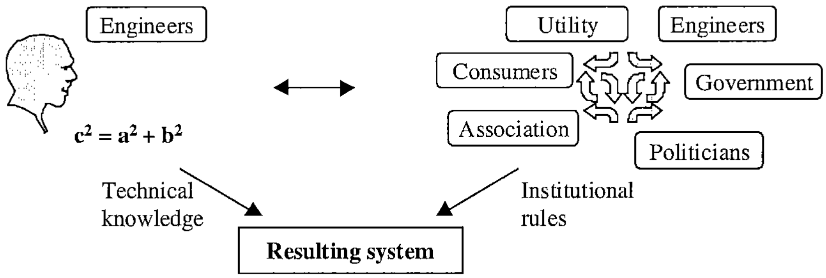

Figure 2.6: Two major influences contribute to the way in which the system is built. Whereas the part termed "technical knowledge" is well known, the part termed "institutional rules" (claims, expectations etc.) is poorly understood.

Institutions are defined as "a significant practice, relationship, or organization in a society or culture" (Merriam-Webster's Dictionary). The theoretical background to this concept is described in section 3.1. At this point, examples are given of how institutions become visible and come to affect water supply systems.

2.2.1 Stakeholder incentives

Incentives represent an important driving force and form part of institutions. All stakeholders have their own incentives to push the design of water supply systems in a certain direction. Some of these incentives are guided:

- *towards the public welfare.* These stakeholders' incentives aim at the best solution to the overall task. Although the judgment of "what is best" is also subjective, it is assumed that there exists an objectively "best" solution with respect to the public welfare. The stakeholders simply want to do a good job. Politicians care for the city and act responsibly, engineers apply their best knowledge and come up with the best possible engineering solutions, urban planners steer the development of the city in its best interests with respect to the water supply, and utility managers apply the best possible strategy to provide the water service.

- *towards personal benefits.* Such incentives stem from the need for prestige, recognition or the elimination of personal fears and doubts. Politicians make decisions guided by impending elections, engineers act in order to obtain more and larger job contracts, planning engineers exaggerate in order to gain recognition, construction companies want to maximize their profits on projects and build them larger than necessary, utility managers want to increase their political influence by expanding their budget.

  These personal incentives are part of human nature. They should neither be denied nor played down.

Both driving forces are continuously applied. They are sometimes contradictory and sometimes create mutual benefits (Brodt, 1999; Melters, 1998). They cannot be switched on or off. They are simply part of the total process of decision-making and acting. How such incentives may influence the decisions of stakeholders will be considered by examining an example of a design process.

During a design process, several steps need to be performed. In each of these, the incentives of a variety of stakeholders are applied and shape the system. The expansion of the capacity of an existing supply system may be taken as an example. The steps involved here are:

- *Formulate goals and design system.* The strategic goals of the supply system are determined in a political decision-making process. Politicians, the utility, the fire service, lobbying engineers and the state authorities are all involved and determine the direction of development. Will the utility be independent of neighboring utilities, will all the demand peaks be covered, etc.? The incentives involved are obviously to maintain continuity of supply, to provide a reliable and safe supply system and to comply with the regulations. But also to get new job contracts, to get re-elected by gaining attention and satisfying consumers or to enhance the political influence and reputation of the utility.

- *Estimate population.* An urban planner takes the lead in estimating the population of the supply area in the year of the planning horizon[3]. The population estimate is based primarily on overall demographic developments. However, political considerations are also included. Politicians determine the intention of the municipality, i.e. whether to grow and expand or to remain small. Personal incentives such as assuming potential responsibility for a large and important city may also be involved. And engineers influence the population estimate by interpreting the numbers and plans of population zones. Population forecasts may be interpreted generously as it is more interesting to build large systems than smaller ones.

- *Determine capacity increase.* The planning engineers estimate the consumption peaks to be expected at the planning horizon. The capacity increase needed in order to meet this estimated demand is then determined. The incentives of the engineers involved are to build reliable but technically ambitious projects. Their professional pride is linked to how technically advanced their buildings are. Reputation among peers can be gained primarily by means of technically innovative solutions. Moreover, large projects are more profitable then smaller ones.

- *Construct new capacity.* Construction companies are mainly responsible for this task. They are influenced by state regulations, by political constraints on the construction procedure and by the utility which supervises the work. Incentives include completing the project on time as well as keeping their own equipment and workforce fully occupied.

Different stakeholders are involved in the planning process. They influence its outcome through their own incentives and by setting incentives for other stakeholders. It is hard to provide a clear description of the reasons and background of such incentives. However, they stabilize stakeholder behavior, which is not expected to change. These stabilizing effects contribute to the establishment of best practices as seen in the following section.

2.2.2 Best practice in engineering

In engineering, "best practice" refers to the current "state of the art". Concepts based on best practice have proved to provide good solutions to standard problems and thus became established over time. Such generally acknowledged concepts are also known as "paradigms". Although these paradigms (or sets of rules) are human constructions, they determine the present world-view of the stakeholders and thus guide current and future action (Denzin and Lincoln, 1994).

[3]The planning horizon is defined as the future year to which the planning process is oriented. The planning horizon is determined by the life-span of the domain object to be constructed. For waterworks, a life-span of 50 years is assumed. But since more than one waterworks is normally present and they are renewed alternately, a planning horizon of 20 years can be assumed (another waterworks needs to be renewed every 20 years).

Paradigms are omnipresent. In economic policy for example, paradigms guide the way in which the state tries to influence the economy (Eisenhut, 1996). From time to time, a new theory emerges which of course influences the paradigm and sometimes results in a paradigmatic shift. In the field of engineering, the concept of best practice strongly influences the way in which technical systems develop. It reflects the characteristic way that engineers practice their art and in which they are predominantly educated (by older engineers). It is hardly feasible to change these best practices and consider new, alternative ways of engineering: individuals must stick to established concepts of engineering and must adjust to their surroundings.

An example of best practice in engineering is shown in Fig. 2.7. The picture on the left shows the traditional way of laying pipes in an angular way. In principle, there is no real technical reason why pipes should be constructed uniquely in this way. Smooth corners (Fig. 2.7, right-hand picture) would offer less friction to the medium transported and thus waste less energy. Nevertheless, the angular approach is the way it's done. Many existing constraints impede the application of smooth corner pipes: all other pipes are constructed this way, all the pipe elements on the market are made this way, no experience is available on the performance of smooth corner pipes, etc. Although smooth corners would be better overall, angular corners continue to be built. Best practice is hard to change since many aspects would have to be considered at the same time. And these aspects are beyond the control of individual stakeholders.

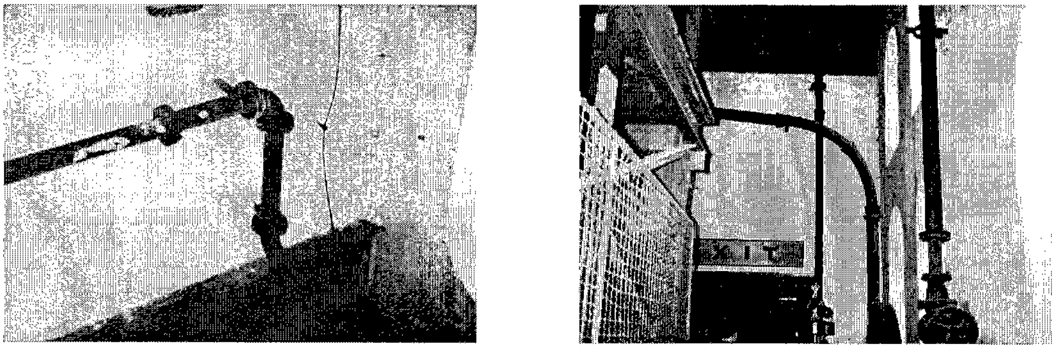

Figure 2.7: *According to traditional engineering concepts, water pipes are mostly constructed in an angular way (left). However, the flow of water through smooth corners (right) would be more efficient.*

Typical best practices related to water supply engineering are:

1. *Worst-case planning.* The infrastructure is designed to cope with all relevant situations and scenarios. Thus considerable uncertainty is inherent in estimating future water demand by consumers. The worst case would be a considerable increase in demand. The infrastructure is consequently built large enough to handle this increase. At first sight, this way of planning the size of any infrastructure seems justified: a bridge is not supposed to collapse even if several heavy lorries cross it simultaneously. The consequences of a failure of the bridge would be catastrophic. Similarly, a water supply system would face serious technical and qualitative problems if water consumption exceeded supply. However, as a result of the worst-case planning paradigm, our infrastructures (roads, water mains, storage tanks, bridges etc.) are used inefficiently most of the time.

2. *Safety factors.* The application of safety factors is another traditional engineering approach. They are applied to design values in order to compensate the uncertainty in the design formulas. Calculated diameters, volumes or pump capacities are multiplied by safety factors in order to increase confidence in the design calculations. Because these

factors are often applied repeatedly at various stages in the design process, there is a tendency to cumulate safety margins.

An alternative to this classical safety-factor approach to design would be to expand the risk considerations and apply a risk-based approach. Error variances could be estimated and the error propagation taken into account. Although such risk-based philosophies are promoted (Freeze et al., 1990), they have not yet received widespread attention in practice.

3. *Extrapolation.* The principle of linear extrapolation is a further example of best practice in engineering. It assumes that past developments may be extrapolated well into the future. Minor shifts in these extrapolated developments may be accepted, but past patterns are generally assumed to continue. No special attention is given to negative feedback loops or to the possibility of change. The viewpoint is rooted in the past, looking forward and assuming that the path of development will continue unchanged (Fig. 2.8).

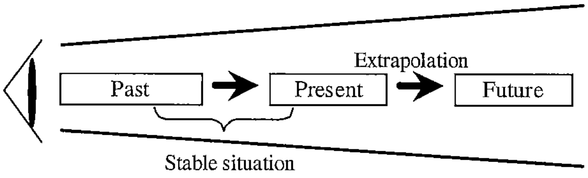

Figure 2.8: *Linear thinking and planning through extrapolation (adapted from Krüger, 1998).*

An alternative would be to take the viewpoint of the future. Clear ideas of opportunities and risks would need to be developed in order to determine the path of minimum risk and to steer developments accordingly (Fig. 2.9).

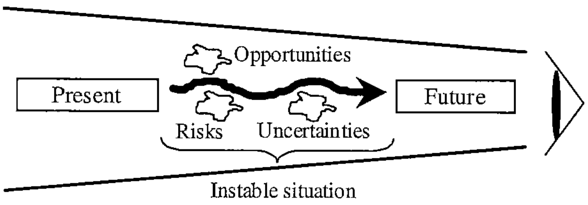

Figure 2.9: *Strategic thinking and anticipation (adapted from Krüger, 1998).*

4. *Income compensation according to size.* The income received by the engineering firms who construct or design the infrastructure is often proportional to the size of the project. As a result, the engineers have no incentive to invest their time in trying to reduce the overall size of the infrastructure. This situation tends to lead to larger projects and buildings.

5. *Centralized system.* A last paradigm which should be mentioned is the construction of centralized systems. Thus reservoirs are designed as central storage facilities serving large parts of a city. A decentralized solution involving individual reservoirs located under the roof of each house or in the neighborhood would also be possible in principle. Nevertheless, decentralization has not achieved wide recognition in Switzerland.

It was certainly valuable to apply these paradigms in the past. They have proved to be generally applicable and are the basis of many textbooks. However, they are all directed towards large, technically complex and centralized systems, a common feature which has shaped the development of today's infrastructure.

Despite the stabilizing effect of incentives, best practices may nevertheless change. During the recession of the last ten years, the focus of stakeholders has shifted from technical aspects to financial ones. This shift may also affect best practices to a certain extent. The past was characterized by an overall faith in growth, and the systems were accordingly designed to grow. In recent years, stabilizing or decreasing trends (e.g. consumption) have been acknowledged and the financial status of the utility moved into clearer focus (debts, water tariffs, investments etc.).

2.3 Conclusions

The conclusions of the above sections are summarized as follows:

- The water supply system is technically static. Its infrastructure is interdependent, occupies most of a utility's budget and generally inhibits innovation. Operational flexibility is achieved by adopting large technical solutions. Political guidelines and the resulting management concepts are supply oriented and are designed to meet all demands. However, recent changes in demand and the environment conflict with the existing system. The utility faces an increasing danger of being insufficiently flexible to anticipate new challenges.

- Many stakeholders influence the system and create changing boundaries. As a starting point, only a selection of stakeholders will be explored further in this research project: relevant stakeholders of a utility are engineering firms, politicians, consumers and the state. The utility of a large city must be selected as a study site and a source of further data.

- Institutions matter because they influence the development of water supply systems, but the extent of their influence is difficult to specify. For example, the impact of institutions as a result of motivations such as "not losing face", or "not wanting to make a mistake" (since mistakes are often not tolerated in our society) are hard to quantify. Incentives and best practices drive developments as well as stabilize behavior over generations. When exploring the behavior of stakeholders (see chapter 4), a distinction must be made between past and present behavior.

Chapter 3

Approaches to institutional analysis

This chapter first reviews the meaning of institutions and then explores research techniques which are suitable for analyzing them. It concludes with the demands with which a methodology should comply in order to reach the goals of the project.

3.1 Institutions

The analysis of institutions, their influence and requirements, is a growing field. In the domain of water resources and water supply systems, Nunes Correia and Krämer (1997) give an overview of institutions in a European context. Minsch et al. (1998) analyze stakeholders (who are organized in and guided by institutions) with the aim of achieving sustainable development. Engel (1997) focuses on stakeholder interactions and their obstruction of innovative and sustainable solutions in agriculture. Bakker et al. (1999) provide a framework for institutional analysis with respect to managing flood and drought risks. Hijum and Goldfarb (2000) compare institutional water-settings in two different countries. The importance of stakeholders is also highlighted and discussed in many other domains such as information systems and management science (Gao, 1997; Schulz, 1995).

The concept of an "institution" is often not well defined and may mean different things depending on professional background and language. It is thus important to distinguish between different types of institutions in order to avoid confusion. The term "institution" can be interpreted in two different ways:

1. Formal, clear, visible, with a written constitution – Institutions with these characteristics are organizations in which the stakeholders are organized (Nunes Correia and Krämer, 1997; Evans, 1997; Breithaupt et al., 1998). Examples are:
    - Organizational structures. They comprise entities such as governments, authorities, banks, insurance companies and common interest organizations.
    - A means of organizing interactions. Examples are the stock market, the market square or a meeting point.
    - Specific or written rules for organizing life in a society. Laws, regulations and written standards (e.g. of a professional organization) belong to this category.
    - Other examples from the social sphere include the family, universities, religions and schools (Hunt and Colander, 1990).
2. Informal, fuzzy, unmanifest, unwritten, shared beliefs – Institutions with these characteristics represent the invisible rules of the game. They regulate the patterns of stakeholder

behavior and simultaneously enable and constrain them. In this sense, institutions consist of cognitive, normative and regulative structures and activities which give stability and meaning to social behavior (Ostrom, 1986; Crawford and Ostrom, 1995; Bakker et al., 1999; Young, 1998; Scott, 1995; North, 1990). Examples are:

- Paradigms. The way things are done. In water supply engineering: supply side management, not influencing demand (see section 2.1). It is nowhere written down how to ensure that everyone can have water every day, but it has always been achieved the same way.
- Habits. People are used to certain hygienic standards and procedures in toilets. When traveling to other countries and cultures, they are often unpleasantly surprised or embarrassed by local habits of hygiene. Thus toilet paper is flushed in European countries but is put into a separate bin in "developing" countries (due to scarce water resources and a lack of water pressure).
- Correct and socially acceptable behavior. Thus you should not go to the opera in blue jeans, even though there is no law against it. If you do, you will be looked at with some disdain.

In the following, the meaning of the term institutions includes *both* its formal and informal aspects.

The *theory* of institutions has played a changing role in sociology, economics and the political sciences (overviews in Soltan et al., 1998; Bakker et al., 1999; Scott, 1995). Neo-classical economics ignores the role of informal institutions. This theory thus fails to acknowledge that not all individual practices are rational and economically sensible. In contrast, institutional economics rejects the methodological individualism underlying neo-classical economics, arguing that behavior is to some extent collectively (or socially) determined, and that social institutions are not imperfections but represent the very structure which allows the market to operate (Jacobs, 1994). More recently, new institutional economics has further de-emphasized the role of choice, strategy and rationality. This form of institutionalist theory has stressed the role of prior (non-rational) choices, common norms and culture in narrowing or expanding the range of acceptable and available options. A further indication of the growing awareness of institutions seen as norms, rules and shared strategies is that the International Human Dimension Programme (IHDP) has established projects on the topic (e.g. (IHDP, 1998).

The *significance* of informal institutions is now generally acknowledged. An understanding of the foundations of social norms, networks and beliefs is assumed to be crucial for explaining much of what takes place in modern economies (Brinton and Nee, 1998). On the one hand, institutions make action easier or even render it possible at all. They reduce the uncertainties of human interaction and form a stable (but not necessarily efficient) order (North, 1990). Institutions allow humans to rely on laws and stable organizations or allow them to make decisions from experience. On the other hand, institutions may block action or at least make it difficult and more costly. As a result, they may hinder people from adapting to a changing world, from acknowledging other people's opinions and from shifting existing paradigms. So it should come as no surprise to find systems that operate for long periods of time with rules that no longer correspond to the prevailing system environment. Institutions can lock people into established ways of thinking. At the very least, the danger exists that the time lag is too long to allow optimal adaptation.

The *development* of institutions is based on individual experience. People develop expectations about how others behave through repeated interaction. Their experience eventually forms recognizable patterns of behavior, leads to the foundation of new organizations or promotes new legal rules (Young, 1998). Of course, full equilibrium is never achieved: organizational structures change, laws are added or standards of etiquette evolve with time.

Correspondingly, institutions influence the development of water supply systems (Fig. 3.1). Together with the technical options (state of thc art) and environmental stability, they contribute to the evolution of the infrastructures and management concepts of the utility. The ensuing system in turn inhibits or promotes certain directions of development. Technical options can be promoted and dictated by the stakeholders through research. In a similar way, the stability of the environment can to some extent be influenced by political activity.

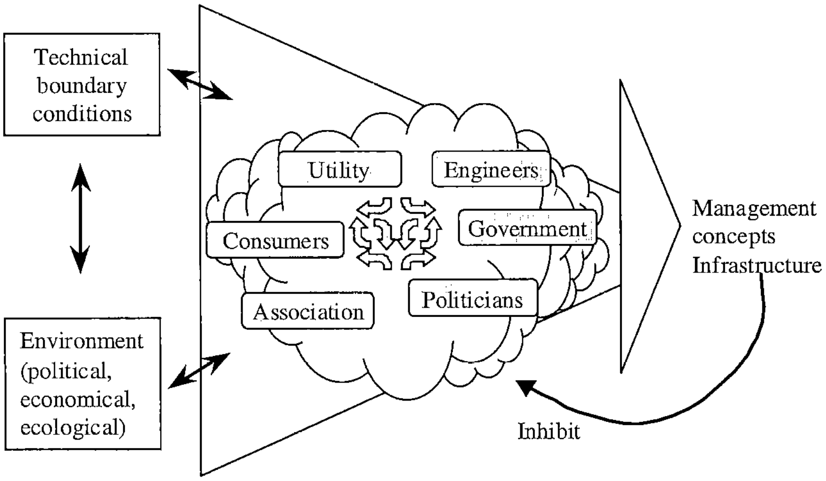

Figure 3.1: *Development and influence of institutions. They are hedged about by technical and environmental options and conditions. In addition, existing infrastructures inhibit the development of new concepts and different types of infrastructure.*

3.2 Research approaches

There is no "best" methodology for tackling the analysis of stakeholder interactions. A variety of techniques and methods can contribute to gaining insight into the questions posed, depending on the nature of these questions(e.g. Grimble and Chan, 1995; Babiuch and Farhar, 1994; Scott, 1991). An appropriate overall methodology needs to be created specifically in response to these questions. Elements are needed from various research disciplines. For this research project, such elements are selected from the disciplines discussed below. The resulting methodology will be described in chapter 4.

3.2.1 Qualitative research

"Qualitative research" is often encountered as a general sociological term. It stands for a whole range of different research topics and methodologies in sociology (overview in Denzin and Lincoln, 1994). The word "qualitative" implies an emphasis on processes and meanings which cannot be measured rigorously (if at all) in terms of quantity, intensity or frequency. In contrast, quantitative studies emphasize the measurement and analysis of causal relationships between variables rather than processes.

Qualitative researchers study things in their natural settings, attempting to interpret and make sense of phenomena in terms of the meanings people assign to them. Hence, this type of research stresses the nature of reality as a social construct. Moreover, it focuses on the relationship between the researcher and the object of study, and emphasizes the value-laden nature of the inquiry.

"Grounded theory" (Glaser and Strauss, 1967) is one of the methodologies applied within the framework of qualitative research. It focuses principally on developing a theory which is grounded in systematically gathered and analyzed data. The theory evolves during the actual process of research, and it does so by means of a continuous interplay between data collection and analysis.

The research tasks of this project (see chapter 1.3) exhibit similarities with qualitative research. An analysis of stakeholder interactions includes qualitative data, an emphasis on processes taking place between individuals and the study of behavior within a socially constructed reality. There is a danger of mixing qualitative and quantitative data, namely of mixing qualitative observations with the results obtained from a quantitative analysis of empirical data. The methodology to be developed must consequently satisfy the requirement of comprehensibility and it must also be possible to reconstruct the results of the study in a straightforward way. It must be clear which of the conclusions are qualitative and which have been validated by empirical data. A promising way of achieving this end may be – in analogy to grounded theory – a *repetitive process* of eliciting, analyzing and documenting data. This procedure will lead to a well-structured research process.

3.2.2 Participatory action research

Like qualitative research, participatory action research (PAR) is not a methodology per se, but rather a cluster of research methods (Greenwood and Levin, 1998; Hollingsworth, 1997; McTaggart, 1997; Stringer, 1996; Whyte, 1990). A common feature of PAR is that some of the members of the organization under study participate actively with the professional researcher throughout the research process. The cooperation starts at the initial design stage of the project and ends at the final presentation of results. PAR contrasts with common types of applied research in the social sciences in which only the researchers themselves act as professional experts. In this approach, these experts design the project, gather the data, interpret the findings and recommend appropriate action to the client organization.

This difference can be illustrated by the following example. Applied social science mostly involves the integration of concepts, ideas and information from the social sciences with those from engineering or the management sciences. Since engineers and managers do not have the time for research which does not directly benefit their daily business, the social scientist generally takes the initiative in attempting to achieve such an integration. However, the conventional way of starting this process of integration is to use the engineers and managers as sources of technical information. They are involved only to the extent of providing technical information and ideas to the scientists.

However, by treating technical specialists as informants, the researcher runs the risk of misunderstanding or oversimplifying their message. The PAR social scientist initially views himself as a participant observer, showing respect for the work of practitioners and technical specialists and seeking to learn from them. This paves the way for establishing a full partnership. As the social scientist gains an understanding of the relevant organizational culture and work systems, he will find ways of using his own knowledge to contribute to the research questions, which have also been mutually defined (Whyte, 1990).

One of the disadvantages of the PAR approach is that it is often time-consuming. Moreover, the success of the research program depends on the personality and communication skills of the researcher.

The PAR approach would appear to be helpful to the current research project. To tackle the incentives and behavior of stakeholders and to study the interactions between them is a politically sensitive task. There is a danger that stakeholders become the object of public criticism for their past behavior. It is easy to question past decisions in retrospect. The results may be misinterpreted and misused by the media, politicians or other interest groups. As a result, the methodology to be developed requires *participation* by the stakeholders from the beginning to the end. A good partnership and an atmosphere of confidence have to be established.

3.2.3 Integrated assessment and focus groups

A further requirement of the methodology may be drawn from the process of Integrated Assessment (IA). IA is a maturing research approach aimed at providing support for making decisions relating to complex environmental problems. It can be defined as an interdisciplinary and participatory process of combining, interpreting and communicating knowledge from diverse scientific disciplines to achieve a better understanding of complex phenomena. Integrated assessment has two main characteristics: (i) it should contain added value compared to insights derived from disciplinary research, and (ii) it should provide decision-makers (and society at large) with useful information (Rotmans and van Asselt, 1996). It puts disciplinary results into perspective, both with regard to their mutual focus and to the points of view and interests expressed by societal actors. The task of integrated assessment is then not only to achieve interdisciplinary harmony, but also to make scientific evidence accountable to the public at large (Kasemir et al., 1999, Jaeger in Bailey et al., 1996).

Various approaches to integrated assessment may be taken. In the first place, the task of IA is achieved by building computer models designed to combine the results from various disciplines. These models represent frameworks for organizing the scientific knowledge within these disciplines. They consequently provide a discussion platform for the participants and decision-makers involved. Secondly, use is made of participatory heuristic methods such as expert judgments and focus groups. The latter are group discussions focusing on specific topics, stimulated by an input and guided by a skilled moderator (Schlumpf et al., 1999; Morgan, 1993).

The essence of this approach is to combine the views held by stakeholders and the public at large with the knowledge evaluated by disciplinary research. This process of integration requires a tool such as a computer model or stimulating questions by a moderator.

The methodology to be developed also requires a *tool* to trigger the information flow between stakeholders. Individual behavior is normally a mixture and result of many influences. It is intrinsically difficult to express behavior clearly. Moreover, discussion of personal incentives and behavior is rendered even less easy by the aggravating circumstances involved in dealing with a taboo topic. The danger of being misinterpreted when acknowledging, say, the importance of making a profit, is considerable (at least in Switzerland). A mediating tool is thus of considerable importance: it may be a computer model, a game board, a questionnaire etc.

3.2.4 Social Simulation

Social simulation is the art of carrying out thought experiments relating to social questions with the aid of a computer. Questions such as the following are typically asked: assuming that the theory about the target system is valid (and that it is adequately translated into a computer model), how would the target system behave (Troitzsch, 1997)?

The term social simulation covers a large cluster of different research fields. Computer simulation is widely used in the social sciences, extending from sociology to economics, from social psychology to organizational theory and political science, and from demography to anthropology and archaeology (Conte et al., 1998). At core, all these applications address the problem of how patterns arise from the actions of individual agents (Hayek, 1942–44).

Computer simulation began to be widely used in the social sciences in the 1990s with the advent of increasingly powerful computers. This introduced the possibility of a new way of thinking about social and economic processes on the basis of the ideas of emergence of behavior (complex or not) from relatively simple activities of the individual agents (Gilbert and Troitzsch, 1999). Real world data need not necessarily be involved, as simulations may also be based on abstract qualitative data.

A main advantage of social simulation is that it can visualize the effects of stakeholder behavior. Their interactions are implemented in a computer model and simulations are then run to observe the outcome of these interactions. The tool thus serves as means of validating the implemented behavior by comparing the outcome with phenomena observed in reality.

The research tasks of this project and the methodology to be developed can benefit from the social simulation approach. By developing a *model* which implements stakeholder behavior, the researcher can visualize both their mutual interactions and their effects. This, in turn, may serve as input for further stimulating the discussion about behavior. A model could also serve as a means of simulating scenarios of alternative behavior. Alternative stakeholder strategies can consequently be tested and their effects on the development of the infrastructure studied.

The next chapter addresses the question of the best approach to modeling the interactions of stakeholders in water supply systems.

3.3 Modeling approach

The approaches which have been developed in order to record human behavior can be divided into two groups. The first group includes theory-driven approaches. They attempt to describe the internal processes of stakeholders and generate a mechanistic model of stakeholder behavior (for overviews see e.g. Jager et al., 1999; Kottonau, 1998a, 1998b; Esser, 1996). Examples are the standard model in neoclassical economics, known as "homo economicus", which is based on the paradigm of maximizing the subjective expected utility (Edwards, 1954). In sociology, the RREEMM model (Resourceful, Restricted, Expecting, Evaluating, Maximizing Man), represents a classical model of human behavior (Lindenberg, 1985). It focuses such that the modeled action essentially accords with the rules imposed by society (norms, roles, constraints; "homo sociologicus" (Dahrendorf, 1958)). Moreover, models of social cognition based on the "Theory of Planned Behavior TOPB" (Ajzen, 1985) also belong to this group. In the field of water supply systems, first attempts to model water consumers have been made (Jager et al., 1999) and serve as a basis for discussing further improvements.

The second group includes pragmatically oriented models. They treat the stakeholders as a black box and base their behavior on "condition – action" rules. Such models have gained recognition in parallel to the development of the discipline of distributed artificial intelligence (Langton, 1989; O'Hare and Jennings, 1996). Distributed artificial intelligence (DAI) is the study, construction and application of multi-agent systems, i.e. systems in which several interacting, intelligent agents pursue some set of goals or perform some set of tasks (overview in Weiss, 1999). Many examples have shown that the development of emergent properties can be explained by the application of relatively simple "if – then" rules to individuals (e.g. water consumers, Schmon and Tarnowski, 1999).

The latter approach is better suited to the purposes of this work. The model must be easy to understand, pragmatic and thus easy to discuss with the stakeholders involved. In contrast, social cognition models tend to be complex and hard to understand for non-experts in the domain. Moreover, no "single" theory is appropriate.

3.3.1 Agents

The basic entities of multi-agent models are agents. Agents are computer representations of stakeholders[1]. Although the term "agent" is widely used, no definition for it is universally accepted. A first definition is that of Franklin and Grasser (1996):

> "an agent is a system situated within and part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future".

A further "weak notion of agency" is given by Wooldrigde and Jennings (1995). According to them, an agent is a software-based computer system that enjoys the following properties:

- *autonomy*: agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state (Castelfranchi, 1995).
- *social ability*: agents interact with other agents (and possibly humans) via some kind of agent communication language (Genesereth and Ketchpel, 1994).
- *reactivity*: agents perceive their environment (which may be the physical world, a user via a graphical user interface, a collection of other agents, the Internet, or perhaps all of these combined), and respond in a timely fashion to changes that occurs in it.
- *pro-activeness*: agents do not simply act in response to their environment, they are able to exhibit goal-directed behavior by taking the initiative.

This definition places greater emphasis – compared to the first one given - on the aspects of autonomy and social skills. A further aspect, namely persistence (continued existence), is mentioned by the definition of Huhns and Singh (1997a). For them, agents are "active, persistent (software) components that perceive, reason, act, and communicate".

Introducing the notion of persistence into the definition of an agent is not appropriate for all agent-based systems. The meaning of the word agent differs depending on the domain. Thus an agent may be a component of agent-based social models of humans (or other living entities). But the term agent must be interpreted differently when considering agent-based systems as large computer systems. In such systems, computers at different locations are interconnected, and agents move from one computer to another. Similarly, the terms autonomy or social ability acquire different meanings when used for agents attempting to mimic human capabilities compared with those used within the context of large computer systems.

In this research project, agent-based models are viewed as social models of humans. The agent definition of Franklin and Grasser (1996) is used.

Many ways of designing agents, both different and similar, can be found in the literature (overviews in Weiss, 1999; Huhns and Singh, 1997b). Agent architectures are characterized by the nature of their decision-making processes. Depending on the phenomena to be modeled, the agent architectures focus on rational, social, adaptive or communicative behavior. Examples of agent architectures include logical-based architectures (in which decisions are made

[1] Use of the term *"agent"* in conjunction with stakeholders and actors often leads to misunderstandings. In everyday speech, agents may be human actors (e.g. espionage agent, sales agent), but may also be parts of computer programs as seen above: when implemented in computer code, actors or stakeholders become agents.

via logical deduction), reactive architectures (in which decisions are made via simple mapping from perception to action), belief-desire-intention architectures (in which decision making is viewed as practical reasoning of the type that we perform every day in realizing our goals), and layered architectures (in which decisions are made by means of the interaction of a number of task-accomplishing layers).

3.3.2 Multi-agent systems

Multi-agent systems have the potential to play an important role in analyzing and developing models and theories of interactivity in human societies (e.g.Gilbert and Troitzsch, 1999; Conte, Hegselmann, and Terna, 1997; Epstein and Axtell, 1996; Castelfranchi and Werner, 1992). Multi-agent modeling (Weiss, 1999) is characterized by the existence of many agents who interact with each other with only little or no central control (bottom up). A particular attribute of multi-agent modeling is the distribution of intelligence (computer code) among these independent agents, as well as their multi-level characteristics. While interaction among agents takes place at micro-level, system properties or variables emerge at macro-level.

Several multi-agent systems have recently been developed to study emergent processes in societies in different domains such as biology (Drogoul and Ferber, 1995), management (Lin et al., 1996), economics (Berger and Brandes, 1998), ethnology (Kohler, 1997) and water supply systems (Moss, 1998).

The main advantage of multi-agent simulation over other approaches is that it allows for the explicit and, at the same time, flexible description of individual behavior. Not only are single entities of the problem domain represented in one-to-one fashion, but so are their actions (Peters and Brassel, 2000). The application of an agent-based technology is especially appropriate for the study of systems focusing on:

- *Behavior*: Agent-based models are well suited to model the behavior of individuals or groups of individuals. Typically, the behavior of, say, stakeholders can be incorporated in rules (code) applicable to the agents. Since agents are independent entities, they need to interact with other agents. Such interactions can be easily depicted and explored.
- *Communication*: Since the intelligence of the whole model is distributed among many agents who represent specific entities of the real world (e.g. stakeholders), such models can be effectively communicated.
- *Qualitative information*: Agent-based models can often include incomprehensible qualitative behavior better than conventional models (e.g. differential equations).
- *Dynamic system size*: Agent-based models also allow the model structure to be variable. The model "grows" during its runtime. More agents are added and others are deleted. This permits the study of evolution and dynamically adapted system size.

These attributes of multi-agent systems are very useful when building a model for the purpose of analyzing the interactions of stakeholders as in this research project.

Over the past few years, a number of frameworks for creating multi-agent systems have been developed (e.g. Minar et al. (1996), Möhring (1996), Moss et al. (1998), Burse (2000), Brassel (2000)). These systems vary from platforms and frameworks for agent development to agent languages (in which agents are written) and agent communication languages describing communications between agents. Such systems have been developed in many programming languages and are targeted at many different applications and user groups (overview in Chauhan (1997), Huhns and Singh (1997b)).

Although such frameworks provide the programmer with a lot of useful help, graphic components and the design and structure of the model, they have the drawback of tying him closely to the framework. Programmers who are not computer specialists and who are new to the field often find it difficult to understand the concepts behind the framework. There is thus considerable danger that an explicit understanding of how such frameworks function will be lacking.

In conclusion, a multi-agent modeling approach seems appropriate to model the interactions and behavior of stakeholders. Such a model structure allows each stakeholder to be depicted as an agent and includes the behavioral rules of the stakeholders in the behavior of the agent. By separating the behavior of different stakeholders and creating different agents, a foundation is created for structuring the model. Moreover, since the behavioral rules of the agents are depicted in a "condition – action" format (as opposed to, say, differential equations), these rules can be understood by the stakeholders. The model can evolve dynamically, for instance if new consumer agents are needed (as the population grows).

The modeling framework is being developed from scratch. After a short trial phase with an existing framework, it became clear that the absence of a complete understanding of the framework design inhibited the creation of a model. The value of a better understanding of a framework developed by the programmer himself is considered greater than the time lost in building the framework. Moreover, the framework can also be built in conjunction with the concepts and design of an existing framework (Burse, 2000). Java will be used as the modeling language in order to ensure compatibility with recent developments in computer science.

3.4 Conclusions

The conclusions reached above are summarized below. The methodology to be developed will be based on:

- a *repetitive process* for eliciting data, its documentation and analysis.
- a *participatory* approach, involving the stakeholders from the beginning to the end. This requires the establishment of a good partnership and an atmosphere of confidence.
- a *tool* to trigger the information flow between the stakeholders.
- a *model* which can be used to implement and validate the behavior and interactions of the stakeholders by comparing the model output against real data. The model will be based on a multi-agent structure. The mechanism used to depict stakeholder behavior will be based on "if – then" rules.
- a *user-defined* modeling framework, which is to be developed from scratch and is designed to provide full understanding of the model. The modeling language will be Java.

According to the above parameters, an enhanced understanding in each of the following four scientific fields is needed in order to make the desired progress:

- *Engineering science.* A solid understanding is required of the technical side of water supply systems: knowledge about how such systems are built, the reasons why they are built in a specific way (from the technical viewpoint), as well as the links between these systems and their related infrastructures (e.g. drainage).

- *Social science.* A knowledge which covers the behavior, interests and strategies of the stakeholders must be gained. Other relevant knowledge includes ways of obtaining the necessary information from the stakeholders, of implementing a participatory process, etc.
- *Computer science.* Because a mathematical model is to be implemented on a computer, this work involves computer sciences, modeling techniques and implementation of the model with the application of appropriate computer tools and a suitable model structure.
- *Economic understanding.* In order to understand the water supply system and the observed phenomenon in full, a good understanding must also be achieved of the financial aspects. This is because the technical and financial developments of water supply systems are linked. In addition, a good background in business management is needed in order to talk intelligibly to financial stakeholders etc.

Chapter 4

Methodology

The methodology is based on the considerations set out in the previous chapter and is oriented to the research tasks defined in this project. Its special characteristics are that it involves stakeholders in a modeling process, that the discussion agenda is based on a questionnaire of proposed behavioral rules and that – once approved – these rules are incorporated in an agent-based model. The combination of these aspects constitutes the essence of the methodology.

4.1 Outline

The methodology consists of several components which will now be outlined in brief (Fig. 4.1). A more detailed description is given in the next section 4.2.

Before starting the process, the knowledge engineer must have a good knowledge of the water supply domain. The term "knowledge engineer" refers to the scientist who initiates and guides the research process. His/her knowledge is based on a professional education in civil and environmental engineering. But he/she must extend this knowledge by studying the relevant literature in depth and by interviewing specific domain experts. Competence in the domain is a precondition for engaging in serious discussions with the stakeholders involved.

Although the following components of the methodology must be performed sequentially, iterative cycles are both possible and necessary (see Fig. 4.1).

Goals. The stakeholders who participate in the process and whose behavior will be characterized below must agree on the research tasks. The participants must share a common understanding of the reasons and necessity for the study. Once agreement is achieved, the process can develop on the basis of common goals and understanding.

Rule-questionnaire. A model containing the rules of behavior and interactions of relevant stakeholders is created by the knowledge engineer. In order to query this model, the rules, i.e. many individual statements of behavior, are summarized in a rule questionnaire. This then provides the basis for discussing the model. The rules may be right or wrong, since they have not yet been validated by the corresponding stakeholders. All the rules are formulated in an "if (condition) – then (action)" form. The overall behavior of the stakeholders is then represented by a patchwork of all these rules taken together. The rules also contain information about the tasks to be performed by the stakeholders, their incentives and their goals.

"Water table". The rule questionnaire is subsequently discussed and answered in a participatory process. Participants in these discussions are the stakeholders whose behavior is modeled. This process produces feedback to the individual questions (the model rules).

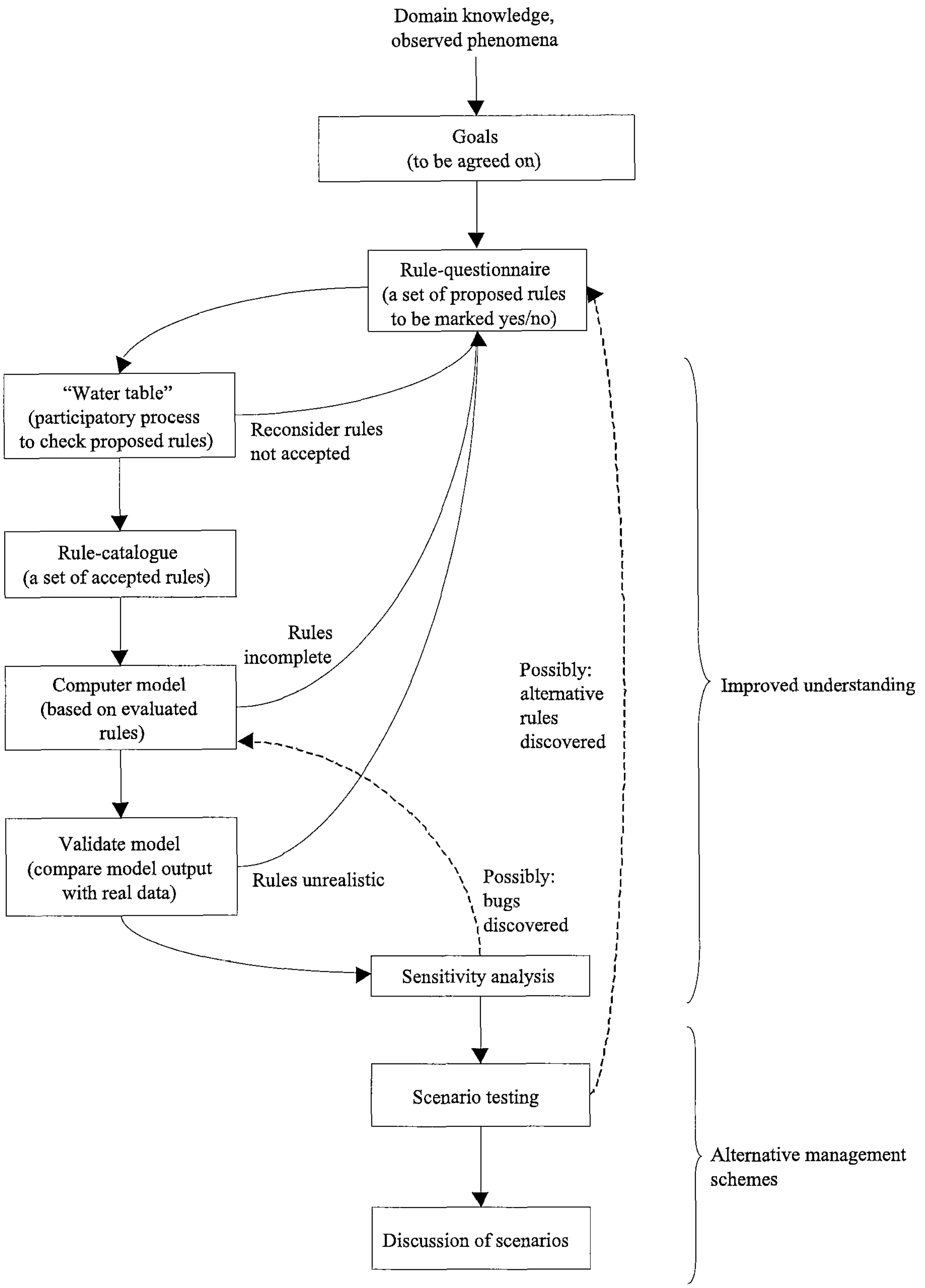

Figure 4.1: *Outline of the methodology. A process designed to improve our understanding of the stakeholders' interactions and decision-making rules leads to a model which can be used to explore alternative rules and hence help to improve management schemes.*

Some of the rules are acceptable to stakeholders, others not. In the latter case, they have to be reworked and submitted to the stakeholders in a new round of discussions. Conflicts during rule elicitation are solved by mediation of the knowledge engineer.

Rule-catalog. This iterative process leads to the emergence of a rule catalog. This is a hybrid of all the rules which were evaluated and accepted in the participatory process (water table) on the basis of the rule questionnaire. Some additional rules which emerge from the discussions are also added. It thus contains a description of behavioral rules (including types of tasks, interests, strategies of stakeholders) to which the stakeholders have agreed fully or in part. The rules must remain partly general and abstract as they are designed to capture the essence of the behavior of the stakeholders.

Computer model. The rules are implemented in computer code ("if-then" equations) on the basis of the rule catalog. The resulting computer model can simulate the development of a water supply system on the basis of these rules. Typical input variables for the model include peak consumption by consumers, while output variables include system capacity, water price or necessary annual investments. Although with the model the development can be simulated over a period of many years, the rules are not changing over the simulation period. The methodology thus neglects the formation or adaption of rules.

Model validation. The model output is now compared with real data from the utility which is being modeled. If the rules produce an unrealistic result, they have to be checked and discussed again. Note that the stakeholders themselves do not see the model result at this stage, but only when the model rules are complete.

Sensitivity analysis. The next step encompasses an exploration of the parameter space and the sensitivity of the model's output variables. Even if the contribution of individual parameters to the model's uncertainty will be hard to determine precisely, the sensitivity analysis enhances understanding of the influences of individual parameters and of the system as a whole. It also acts as a check to determine whether the model is poorly implemented (bugs).

Scenario testing. Finally, once the model has acquired credibility, it can be used to perform scenarios. In the first place, the performance of the existing rules can be evaluated with respect to a future demand scenario. Secondly, the effects of alternative rules can be tested. What would happen if water consumption dropped in future and the same rules continued to be applied as in the past? How would the system develop on the basis of alternative rules? Scenario testing yields ideas for alternative rules which could also be discussed.

Discussion of scenarios. The results of these scenarios are discussed with the stakeholders involved. Their intuition regarding the system can then be compared with the simulated development of the utility. Lessons can be learned and new ideas and concepts generated and discussed.

In the next section, the components of the methodology are described in more detail.

4.2 Components

Note that in this chapter the methodology is described in a general sense. A specific application is examined in the case study treated in chapter 5.

4.2.1 Goals and rule-questionnaire

The process of agreeing on the goals of the research must not be underestimated. The motivation of the stakeholders to participate in the project is crucial for its success. The involvement of the stakeholders at the stage of defining the goals creates the basis for this motivation.

The rule questionnaire is a document comprising the suggested rules of behavior of the stakeholders. Since they have not yet approved the rules, multiple-choice boxes are added which should be duly marked. The statements they contain may be completely true, partly true or wrong.

Table 4.1: *Example of the structure of the rule questionnaire. Each stakeholder is described and characterized. The description includes the stakeholders' tasks, interests (goals) and the strategies they use to achieve these goals. All these characteristics are expressed in concrete terms on the basis of rules. Beliefs are taken into account as parameter values. These rules are seen as the proposed basis for a discussion with the stakeholders.*

Example characterization of the chief engineer of the utility	Agreed? yes	partly	no
Tasks: (Example)			
a) Check whether capacity must be adapted to recent developments in consumption	☐	☐	☐
Interests: (Example)			
Technical perfection	☐	☐	☐
Strategy used to realize tasks and interests: (Example)			
Past: Worst-case planning	☐	☐	☐
Present: Average-case planning	☐	☐	☐
Specific rules for task a): (Example)			
Past: *If* existing capacity reserve is less than 20% with respect to last year's consumption peak, *then* increase capacity.	☐	☐	☐
Present: *If* existing capacity reserve is less than 5% with respect to last year's consumption peak, *then* increase capacity.	☐	☐	☐
If capacity needs to be increased, *then* apply a planning horizon of 20 years.	☐	☐	☐

Each stakeholder (individual or group) involved is first characterized by his typical *tasks*. These tasks describe his or her responsibilities with respect to the situation modeled in the process. Secondly, the general *interests* of the stakeholders are described in order to provide a general background to their motivation. They are merely outlined in a few words and naturally cannot replicate the whole truth, but they do indicate the general incentives for the stakeholders' actions. Thirdly, these interests have consequences expressed by formulating *strategies*. A distinction is made between past and the present strategies. It is needed for two reasons: firstly in view of the changing boundary conditions – specifically the financial ones (see also chapter 2). Secondly, such a differentiation allows stakeholders to free themselves from an identification with past strategies which may seem doubtful in retrospect. Finally, the specific *rules* are as simple as possible; they are understandable and are framed by an "if

– then" structure. Here too, some rules distinguish between past and present situations. The beliefs of the stakeholders are incorporated in the rules as parameter values. All decisions to be made are thus captured by this structure. Relationships to special situations are again set up by "if – then" rules. Cognitive rules are not included at this stage of the model. An example of a rule questionnaire is given in Tab. 4.1.

4.2.2 Participatory process ("Water table")

The rule questionnaire creates the basis for the participatory process. This simple tool is needed to organize the discussion and to stimulate or even provoke the participants. It acts as a starting point, defines the agenda of the meetings and offers a means of recording the stakeholders' ideas. The participants in the discussion are the stakeholders, who are duly described and modeled. The number of participants therefore corresponds to the size of the model. Their professional position (director, head of department, employee) should be selected according to the requirements of the model. The rules of the questionnaire are discussed, criticized and possibly changed in order to improve them. During the participatory process, the stakeholders involved can agree or disagree with the proposed rules and mark their choice accordingly. However, additional tasks, interests, strategies and rules could also be defined, thus adding further details. In order to break up existing hierarchies during the discussion and to compare the results of different types of sessions, the rules are presented to the stakeholders in three different formats:

- *Round-table.* All the stakeholders involved discuss the rules at the same table. Each stakeholder's rules are therefore also discussed by the other stakeholders present. This format has the advantage of allowing the opinion of a variety of stakeholders to be heard on each question. In case of conflicting opinions between stakeholders, the knowledge engineer attempts to obtain agreement.

- *Round-robin.* The stakeholders are involved on a round-robin basis, i.e. the knowledge engineer (who proposes the rules) discusses their set of rules separately with each participant. This format reduces group dynamics, eliminates hierarchies at the round table and permits a more personal and thus confidential relationship. In addition, informal information may be obtained in this way, including proposals for new rules applicable to other stakeholders.

- *Telephone inquiry.* Specific rules are discussed on the telephone with individual stakeholders.

The questionnaire can optionally be mailed to the participants in advance of the discussion rounds. Participants are then asked to answer the questions, mark their degree of agreement (yes, partly, no) and bring their selected answers along to the discussions (round table or round robin).

During this process, the rule-proposing knowledge engineer acts as a facilitator and seeks agreement if the stakeholders hold diverging opinions on certain rules. Non-accepted rules must thus be changed, re-evaluated and reconsidered. Rules which are only partly acceptable tend to over-generalize an issue. Some rules may not allow straight answers to be given. They will need to be formulated better and adapted according to the discussion. Moreover, new rules are also established. A great deal of attention must be paid to their formulations. Rules must often be formulated in a more differentiated manner in order to be correct.

While discussing the rules, it is important to keep the level of abstraction of the overall model in mind. Specifically, it must be clear to the stakeholders that their behavior will be depicted in a simplified manner which does not incorporate the details of their daily business. It has to be clearly communicated that at this stage of the investigation it is more important to evaluate rough rules for many stakeholders of the system than to delve deeply into the behavior of a single stakeholder. Another precondition is that the rules remain understandable to other stakeholders who are not directly involved in the round-table process.

4.2.3 Rule catalog

The above process transforms the rule *questionnaire* (see Tab. 4.1) into a rule *catalog*. The rule catalog contains agreed rules as well as rules which are only partly accepted. It thus represents an answered and expanded form of the rule questionnaire. Tab. 4.2 shows an example of a rule catalog which characterizes the stakeholder representing the chief engineer of the utility. Task b) was added to the tasks listed in the questionnaire: the water meters have to be read in order to determine the amount of water used.

Table 4.2: *Example of the structure of the rule catalog. The stakeholders mark their degree of agreement. Some rules are generally accepted, others only partly. More rules may be included in the catalog than those listed in the questionnaire.*

Characterization of the chief engineer of the utility	Agreed? yes	partly	no
Tasks: (Example)			
a) Check whether capacity must be adapted to recent developments in consumption	☒	☐	☐
b) Determine water consumed	☒	☐	☐
Interests: (Example)			
Technical perfection	☒	☐	☐
Strategy for realizing tasks and interests: (Example)			
Past: Worst-case planning	☒	☐	☐
Present: Average-case planning	☒	☐	☐
Specific rules for task a): (Example)			
Past: *If* existing capacity reserve is less than 20% with respect to last year's consumption peak, *then* increase capacity.	☒	☐	☐
Present: *If* existing capacity reserve is less than 5% with respect to last year's consumption peak, *then* increase capacity.	☒	☐	☐
If capacity needs to be increased, *then* apply a planning horizon of 20 years.	☐	☒	☐
Specific rules for task b):			
If water is used, *then* 65% of it is generally used by local residents and industry, the rest by other consumers (partners, fountains) or else is accounted for by losses.	☒	☐	☐
etc.			

In the example (Tab. 4.2), the rule relating to the planning horizon is only partly accepted.

The age and condition of the remaining waterworks as well as the financial and political situation are also relevant factors. However, this rule represents a good first approximation. To mark it as only partly correct leaves room for interpretation and suggests that its correctness depends on the specific situation.

It is crucial to consider the overall process when reviewing the rule catalog. Although an engineer acknowledges that it is important for him to design the infrastructure with technical perfection, this simple interest may not capture all relevant issues. Additional interests concern the reputation of the utility, his actual position within the management structure, legal liability concerns, personal career perspectives etc. Thus, if the rule catalog is reviewed without a consideration of the whole process and without understanding the simplifications involved, a superficial impression may be left and significant skepticism may result. It is important to understand the degree of abstraction and simplification of the rules, and this is achieved by being involved from the beginning.

4.2.4 Computer model

The computer model is built on the basis of the rules of the catalog. The size of the model as well as the number of its links and boundaries are determined by the content of the rules. All issues which are incorporated in the rules must be implemented in the model. Similarly, what is left unsaid in the rules will not be included in the model. Although the computer model is constructed after the rules have been evaluated, it may also motivate a serious treatment of the rule-finding process.

Moreover, the model is used to check the completeness of the rule catalog (if certain rules are missing, a functioning computer model cannot be set up). Missing rules must be evaluated and discussed in a further round of discussions with the stakeholders.

The model structure follows the considerations outlined in chapter 3. This is a multi-agent structure with reactive agents and a time-driven scheduling mechanism (see also Appendix C). The smallest time step for action is chosen to be a month, since no decisions are made on a shorter basis (e.g. daily). In each time step, an action is performed according to the rules of the agents.

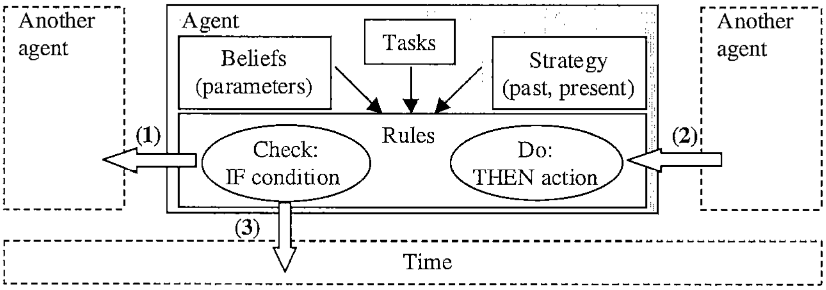

Figure 4.2: *Design of an agent. The tasks, strategy (past or present) and beliefs (the parameter values in the rules) provide the foundation for the rules. The rules consist of a condition part and an action part. The action of an agent can be triggered by a threefold mechanism (see text).*

The design of agents is kept simple (Fig. 4.2). An agent's action can be triggered by a threefold mechanism. First, the agent checks at every time step (or within his own schedule) whether or not to perform a certain task (1). To do this, the agent may consider his condition rules. If these state that some action needs to be performed, the action rules are triggered and determine what is to be done. Second, an agent's action rules can be triggered directly by other agents (2). And third, some agent action rules are executed without a condition or are triggered directly on a time basis (3) (e.g. do task 1 every year).

These rules are transformed into computer code in the following way. The third way to trigger action (see above) will be taken as an example. According to the rule catalog (see Tab. 4.2), the chief engineer of the utility performs an annual check involving two tasks: firstly whether or not to adapt capacity and secondly to determine the amount of water consumed. In the model, the agent checks at every time step whether or not to perform these tasks (Fig. 4.3):

```
If (month equals 1) {
  checkCapacity();
}

If (month equals 12) {
  readWaterMeters();
}
```

Figure 4.3: *Example of code to trigger tasks of Tab. 4.2.*

Task 1 (check capacity) is executed every first month of the year. In this case, the specific rules of the utility's chief engineer require the amount of reserve capacity to be checked (Fig. 4.4). If insufficient reserve is available, a new design process is activated. If an action needs to be performed, then the action rules of the stakeholder are followed. It may be necessary to consider more conditional rules and to trigger a whole chain of condition – action events. In computer code, this task is implemented as indicated in Fig. 4.4:

```
checkCapacity() {
  cap  = existing_capacity;
  res  = wanted_capacity_reserve;
  peak = recent_consumption_peak;

  if (cap - res < peak) {
    start_planning();
  }
}
```

Figure 4.4: *Example of code for checking whether new capacity has to be planned according to the rules in Tab. 4.2.*

The design of the agents is static. The rules do not evolve or adapt to new situations. Once set, condition and action rules remain fixed and unchanged. The trade-off between the sophistication of a single agent as opposed to the size model and the involvement of empirical data is won by the latter.

The following attributes therefore characterize the model: it is stochastic (the model contains elements of randomness), linear (all equations of the rules are linear), dynamic (the output variables evolve over time), discrete in time (since the agent operates with rules and not with, say, differential equations, the model is discrete in time, the agent reacts at specific time steps), and uses reactive agents. Reactive agents involve the implementation of a decision-making process by direct mapping from situation to action (Wooldridge, 1999).

4.2.5 Model validation

The first step of validation is taken during the participatory process. The rules suggested by the knowledge engineer are checked and thus validated by the stakeholders. In contrast, the rules proposed by the stakeholders themselves are excluded from this first step validation.

The second step of validation is achieved by comparing the model output with the observed development of the modeled supply system (historical data). In this step, the overall model (the combination of all rules) is tested. This step enhances the confidence that the set of rules obtained can be used to mimic the observed development and that the rules are plausible.

When comparing modeled and observed data, no quantitative validation criteria are applied. Validation is based on a qualitative assessment since the degree of fit is not of primary interest. However, this qualitative assessment is supported by running scenarios with changed parameter settings (sensitivity analysis, see next section). For each run a simple measure for the deviation between model and reality is calculated. If the model to be validated gives better such fitness measures than the ones of the scenarios, this would enhance the trust in the model.

The model is not validated against data of another, similar city due to time constraints.

4.2.6 Sensitivity analysis

Sensitivity analysis is an important step in the methodology designed to explore the uncertainty inherent in the model. The overall uncertainty includes the model uncertainty (model structure, including boundary conditions) and the parameter uncertainty (input parameters, model parameters and rules). Since only a basic explicit understanding of the behavior and interactions of the stakeholders is available, it must be assumed that the model's uncertainty is large.

The uncertainty regarding model structure is analyzed by changing the boundaries and the range of stakeholders modeled. Different model structures containing different stakeholders (number, type) and their mutual interactions are tested. The uncertainty resulting from the input parameters depends both on the quality of the collected data and on the process of simplifying this data. The uncertainty of the model rules which represent the behavior of the stakeholders can be explored by changing the rules little by little. Uncertainty in the rules is particularly difficult to tackle since they are designed to cover a wide range of situations. However, the uncertainty is already significantly reduced when the model rules are discussed with real-world stakeholders.

As regards the uncertainty of the parameters, best parameter values can be fitted by using parameter estimation techniques when comparing the modeled output variables with the observed development of the same variables. However, such techniques would appear to be inappropriate for this model. Despite the discussions held with stakeholders, the level of intrinsic and parametric model uncertainty is still assumed to be large. The stakeholders are modeled only in general patterns. Accordingly, this situation precludes the use of analytical procedures to determine the "best" estimate for the model parameters given the assumed structure of the model (in analogy to the work of Hornberger and Spear (1981)). Instead, a range can be defined for each parameter value in the model (parameter space). The range is defined by adding or subtracting a certain value to/from the default value of the parameter which is found when the rules are determined. This parameter space is then explored in order to obtain an impression of the model's sensitivity with respect to its parameters. The analysis is performed in the following way:

- A single parameter is changed incrementally within its range. A simulation run is performed for each parameter value (starting at the lower end and working up to the upper end). All other parameters retain their default value. This offers the advantage of allowing the effect of this single parameter to be observed, assuming that the default values of the other parameters are reasonable. The number of simulation runs is defined by the increment between two subsequent parameter values and the parameter range.
- All parameter values are randomly changed within their range (Monte Carlo method).

The number of simulation runs performed must be large enough to capture the whole range of relevant outputs.

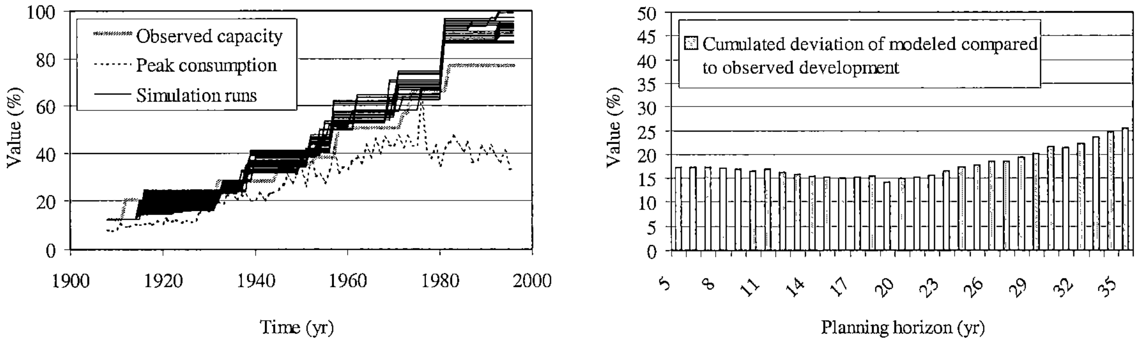

Figure 4.5: *Example of the two forms of sensitivity analysis. See text.*

The non-discrete development of many output variables (e.g. capacity) makes it difficult to compare the various simulation runs. A twofold strategy is thus adopted to analyze the sensitivity of the model to changing parameter values (Fig. 4.5). First (left), the development of the output can be viewed visually. All the runs are depicted at the same time. The variables developed in each run then overlap. A cluster of curves thus emerges which gives an impression of the range of deviations from the output developed on the basis of default values. Second (right), a very simple formula is chosen in order to give an approximate indication of the degree of fit (compared to the observed development) of the individual runs and thus make them comparable. The deviation between the modeled and observed output variables is compared for each run. At each time step, the deviation is calculated and cumulated over the whole run. The equation used to calculate deviations is as simple as possible:

$$\sqrt{\frac{\sum_{n=1}^{n}(modeled - observed)^2}{n}} \tag{4.1}$$

Note that in the case study (chapter 5) only the parameter uncertainty is analyzed and no comprehensive Monte Carlo simulations are performed due to time constraints.

4.2.7 Scenario testing and discussion

The scenario simulation and discussion are the final components of the overall methodology. The main input for the scenarios is an assumed development of consumption. Three different types of simulation are performed. The performance of the stakeholders' rules is evaluated:

- against abstract patterns of consumption development. Different patterns of consumption are defined and subsequently used as the input for the model. The capacity-building rules are now evaluated. What infrastructure dimensions would result from the rules when different consumption patterns are taken into account? The rules can also be altered and simulations can be performed with sets of rules relating to various strategies (past and present). The performance of the two rule sets with respect to different consumption patterns can then be discussed.

- with respect to a future consumption trend. The starting point for these simulations is the modeled state of the utility at the end of the validation period (Fig. 4.6). A future consumption trend is now assumed and the development of the utility simulated according to the stakeholders' rules. Again, both rule sets (past and present) can be tested and the difference in their performance evaluated.

- considering special cases. For example, how would the infrastructure have developed if certain consumption peaks of the past (in the validation period) had failed to occur? In other words, what is the value and effect of such peaks?

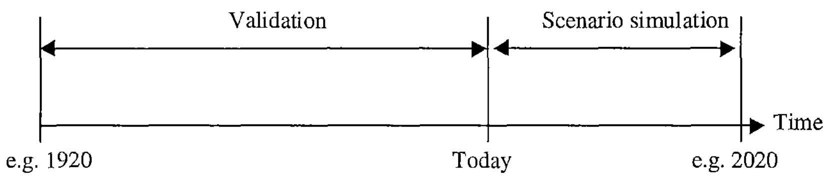

Figure 4.6: *Looking back and looking toward the future. The validation phase compares the modeled output with actual past developments. The scenario simulations of the future assume a certain development of consumption and "predict" the development of the required infrastructure according to the model rules.*

The results of the simulations are shown to the stakeholders and their reactions are discussed. The model output is compared with the intuition of these domain experts and potential differences are explored. However, it is clear that such scenarios have to be considered together with the uncertainties in the model structure and the parameter values. Nevertheless, if these scenarios are regarded as a thought experiment or an "idea generator", they can indicate gaps in the present intuition of the stakeholders. They may thus reveal unfavorable side-effects of well-meant behavior or confirm the expectations of the stakeholders.

In the next chapter, a case study is performed on the basis of the methodology presented here.

Chapter 5

Model development and validation (case study)

In this chapter, a case study is performed in order to test the methodology developed (as described in the previous chapter). The second goal is to address the remaining research tasks as set out in chapter 1. The model described in this chapter can replicate the general development of both capacity and cost-related variables on the basis of rather simple rules of stakeholder behavior. The sensitivity analysis performed indicates that no particular parameter of the engineering rules dominates the development of the infrastructure. It is suggested that the development of consumption, especially its peaks, and the strategies applied (rules), constitute the significant contributors to the development. This hypothesis will be further explored in the subsequent chapter on scenario simulations.

5.1 Definition of system

5.1.1 Utility investigated

A water utility of a Swiss city was chosen as the object of the case study. The city in question has more than 50,000 inhabitants, but its name will not be disclosed. As politically sensitive issues may be explored in the study, they should not become linked to a single utility and its stakeholders involved. Rather, the goal is to reveal general patterns of behavior and their effects on the infrastructure and management concepts. The utility under study merely provides one example of a concept and method which are generally applicable.

The utility was selected for the following reasons:

- The utility is a "stand-alone" facility. It is independent of other state utilities (waste disposal, gas, electricity), and is responsible for its own financial affairs. This means that its overheads cannot be shared with other utilities within the city (or region). This situation ensures financial transparency for the water-related business. Costs are clearly related to the water service and exclude the services of other utilities.

- The utility produces its own water. If water were to be imported from neighboring cities, the model's system boundaries would have to be expanded, thus making it larger and more complicated.

- The history of the utility is well documented. Data for the historical development of its capacity, population, financial parameters etc. are available. This data is important for validating the model output.

- The existing historical data is well maintained, thus minimizing the danger of misinterpreting data due to its poor maintenance.

- The utility's historical data encompasses visible trends. This is important when comparing the trend emerging from the model results with the observed trend, which is also typical for the Swiss situation.

- Finally, and most importantly, the utility management and other stakeholders involved with the utility agreed to participate in this project.

5.1.2 System boundary

The system boundary is drawn in accordance with the research tasks. The model incorporates the relevant stakeholders but is simultaneously kept as simple as possible. As outlined in chapter 2, the model includes the following stakeholders and domain objects (Fig. 5.1):

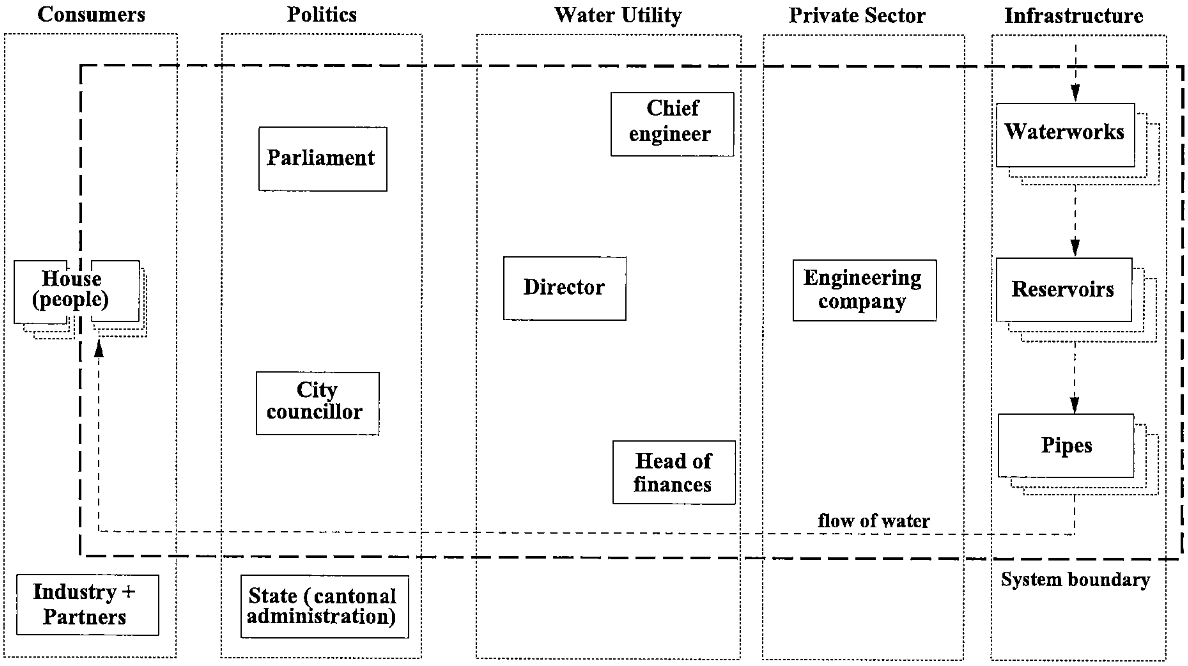

Figure 5.1: *Model diagram showing the water supply system of a Swiss city in simplified and abstract form. The system boundary (dashed line) is selected to be as narrow as possible, but broad enough to address the research tasks. The dashed arrows mark the flow of water from the water source through the infrastructure to the consumers.*

The *utility* is represented by three main stakeholders: the chief engineer, the head of finances and the director. The chief engineer embodies all the planning, designing and technical behaviors (expressed in rules). Although many engineers are employed by the utility, the chief engineer is responsible for the technical aspects. The head of finances represents all the rules relating to the finances of the utility. The director holds a position in between these two main stakeholders and has to coordinate between them. Both the chief engineer and the head of finances make requests (e.g. proposals for more capacity or a higher price) to the director, who takes account of both viewpoints as well as his own policy considerations and then decides on the proposals.

The *private sector* is represented by one engineering company. In the past, competition was almost nonexistent and a single engineering company had the privileged position of "house engineer" (more companies and thus competition could be introduced at a later stage of the model). The tasks of this engineering company must not be confused with those of the utility's chief engineer. Whereas the latter is primarily concerned with planning tasks, the engineering company is responsible for constructing the infrastructure and receives its assignments from the utility's chief engineer.

Private *consumers* and commercial enterprises are summarized in houses. Each house comprises 1000 inhabitants as a model assumption and is implemented as a single agent. Houses are only partly modeled: the development of the annual average and maximum, daily consumption is obtained from a database (and is therefore outside the system boundary in Fig. 5.1). The modeled behavior of houses includes an opinion. The opinion reflects the degree of satisfaction felt by the consumers with respect to the water service. For the simulations of the future (but not for the validation phase) a price-sensitivity and a peak-reduction potential are also modeled. Industry and partners (neighboring cities) are responsible for a significant part of the overall water consumption, but are not modeled explicitly. Their part in the total water consumption is mapped externally in the model.

Similarly, the state (cantonal administration) is a major player but is also treated as an external influence. The state defines the principles of accounting, the levels of subsidies etc. The *political sector* is further represented by a city councillor (executive) and a member of parliament who represents the parliament as a whole. Although these politicians are the final decision makers, they are only modeled in a rough way (a more detailed description would require further political and economic studies).

The *infrastructure* is represented by waterworks, reservoirs and pipe mains. One pipe object stands for 1000 meters of pipes. As the model develops and the size of the infrastructure network grows, more infrastructure objects are added according to the rules of the stakeholders involved. The size of the modeled system thus grows dynamically with time.

5.1.3 Modeled time period

The modeled period ranges from 1908 to 1996. The starting point is chosen because the utility is well documented back to this date. The end point is similarly defined by the available processed data. This modeled time period covers the life-cycle of the infrastructure of up to 80 years. This is particularly important since the stakeholders' actions relate to the replacement or adaptation of the infrastructure.

5.1.4 Model inputs

Both financial and technical values are needed as input to the model (Fig. 5.2):

- *Subsidies* are paid on investments by the state and by the state-owned insurance company for buildings (Fig. 5.2, left). Thus the state subsidizes investments in order to promote infrastructures of regional and national significance (Wasserwirtschaftsgesetz, 1991). In contrast, the subsidies paid by the state-owned insurance company for buildings aim to improve the fire safety of the buildings by providing an adequate pressure and quantity of water in the pipe system (Staatsbeitragsverordnung, 1991). These two reasons for granting subsidies on investments accounted for approximately 20% of total expenditures in the past, and this figure was reduced step by step after the 1980s to 10% in 1996.

- *Connection fees* have also decreased gradually since the end of the sixties (fig. 5.2, left). They are charged by the utility when a new house is built and connected to the pipe

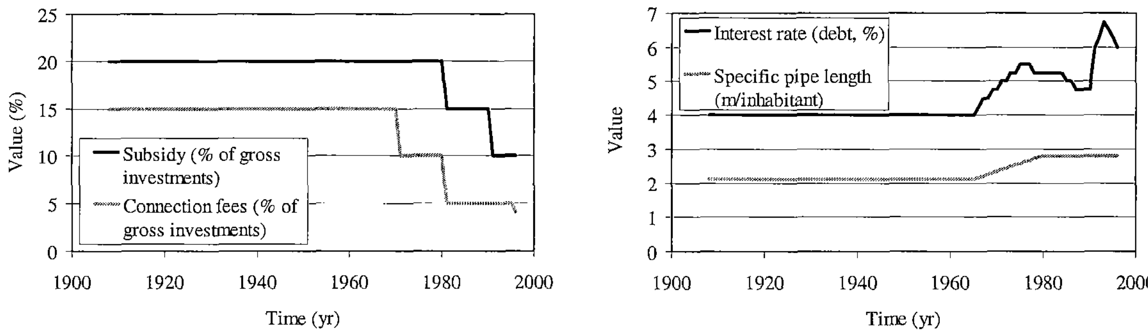

Figure 5.2: *Input parameters of the model. The values are based on real developments of the modeled utility. They show how a rapid change in the rate of subsidies and interest has taken place over the last 20 years. See Appendix B for references.*

system and are justified by the increased value of the property when it is connected to the supply network. Because the population of the supply area decreased after 1970, the percentage of connection fees relative to investments also declined. Annual connection fees are currently in the region of 4% of gross investments.

- *Debt interest rates* have varied in the last 30 years as shown in Fig. 5.2, right. Although they also changed before 1965, they are assumed to average 4%. This simplification can be tolerated because debt levels were minor prior to 1970 and had no major influence on the financial status of the utility.

- The *specific pipe length per inhabitant* is another input parameter to the model (Fig. 5.2, right). The pipe network grew in line with the growth of the population and thus the expansion of the area to be served. During the first half of the century, a rate of about 2.1m/inhabitant was sufficient. The population of the area served declined around 1970 as many people moved out of the city. However, the network could not be reduced immediately in response to a declining population. Therefore, about 2.8m/inhabitant of pipe mains are present today (which is rather a low figure compared with other Swiss cities).

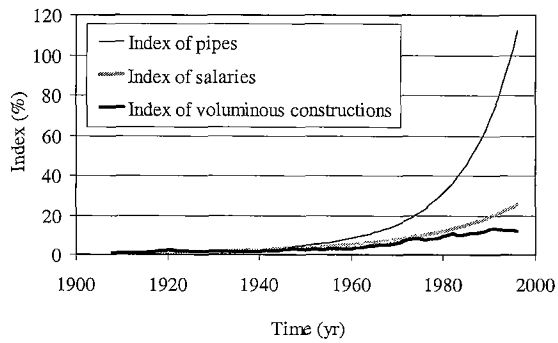

Figure 5.3: *Further input parameters of the model. The values are based on real developments of the modeled utility. Three different inflation rates are specified in order to account for overall inflation.*

- *Inflation* is another highly significant input to the model, as we run it over a period of 88 years (Fig. 5.3). Inflation rates differ for different aspects. Three different rates are included in the model: 1) for construction costs of waterworks and reservoirs (general index for high-volume constructions), 2) for construction costs of pipe mains (affected by increasing traffic), and 3) for salaries of the utilities' staff. Inflation of pipe construction costs exceeded that for other constructions by a factor of about ten. Overall, the price for one meter of pipe is 100 times greater today than it was a century ago.

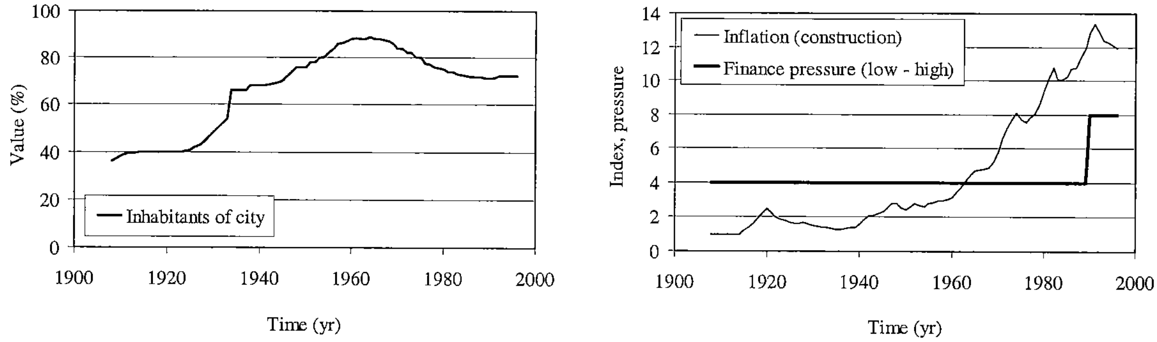

Figure 5.4: *Further input parameters of the model. The values are based on actual developments for the modeled utility.*

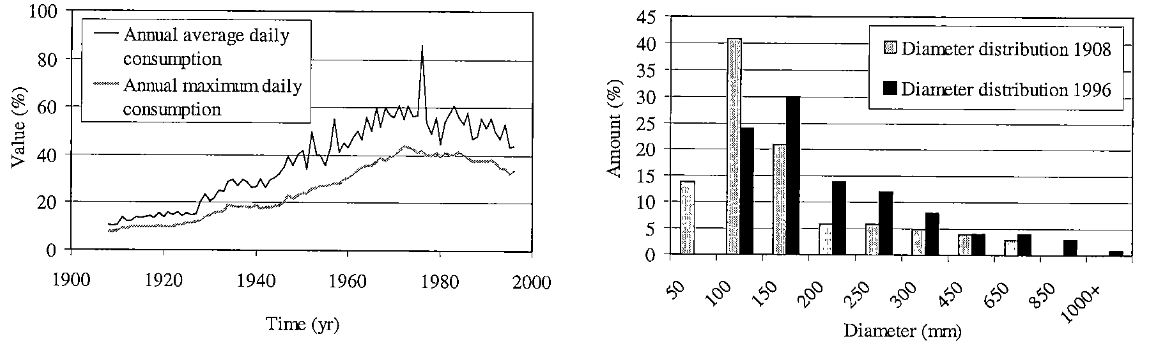

Figure 5.5: *Further input parameters of the model. The values are based on actual developments for the utility.*

- *Population growth.* The development of the city's population is seen in Fig. 5.4, left. The population also increased because a number of suburban municipalities merged with the city, thus resulting in a sharp increase (see figure). The city's population peaked around 1965.

- *Financial pressure.* The financial pressure on the state is difficult to assess. As a first approximation, the recession in the years after 1990 can be considered a period of high financial pressures. The economic slowdown is also reflected in the general inflation index for construction, which clearly decreased during this period (Fig. 5.4, right). The other periods of recession (around 1974 and 1980) are *assumed* not to affect the financial pressure on the state (with respect to water supply systems) as they were shorter and occurred at times when the financial resources available to water utilities were unquestioned. These arguments are not really conclusive but will be accepted for the moment since the influence of the recession after 1990 (with a shift to a strict financial focus) needs to be emphasized (a refinement of the argumentation of this input parameter in a further model stage is suggested).

- *Consumption.* The average and maximum annual daily consumption figures are provided as a model input (Fig. 5.5, left). The utility managers have to react to the development of these consumption values and plan the design of adequate infrastructures accordingly.

- *Diameter distributions* are given for the initial (1908) and final (1996) years (Fig. 5.5, right). Pipe diameters are calculated in the model so that the resulting final distribution is similar to the one observed. As new pipes are built, their diameters are interpolated to eventually match the observed diameter distribution in 1996. No geographical information system (GIS) underlies the model to show the relationships between the location of the pipes and their corresponding diameters (large near the pumping station, small towards the outskirts of the pipe network).

A last input to the model is the *accounting strategy*, which is defined by the state. This strategy changed in 1972 and 1986. These changes are specified in the rule catalog in table B.32 on page 147. Specifically, the targeted depreciation rate changed in 1972 from 2% to a varying rate between 2% and 6%. In 1986, the rate was changed again to 4%.

5.2 Characterization of stakeholders

The information required to characterize the stakeholders was gathered in the participatory process, which involved the following experts:

- the director of the utility
- the head of finances of the utility
- the head of quality assurance of the utility
- the director of the professional water association
- the director of a relevant engineering company

A chief engineer (of operations) of the utility and the responsible city councillor were involved to a partial extent. In addition, enquiries were addressed to several other domain experts (predominantly engineers) about the art of water supply engineering.

The professional water association is not included in the model, although its representative was involved in the participatory process (he was already part of the process before the model was built and before it was decided to exclude the association from the model). His inputs were nevertheless most valuable. On the other hand, a member of parliament was included in the model but was not represented in the discussions in order to limit the number of participants in the process. Correspondingly, his behavior is only described in general terms. Although consumers are at least partly modeled, no specific consumer representative formed part of the discussion group. The rules of consumers were contributed by the knowledge engineer.

The number of discussion rounds included:

- 3 round-table sessions
- 3 round-robin sessions

- approx. 10 individual meetings with domain experts not necessarily related to the modeled utility.

The characterization of the stakeholders involved is documented in the rule catalog. Some stakeholders are modeled in great detail, others to a lesser degree. Only their tasks, interests and strategies are described at this point. The specific rules can be found in Appendix B. In total, 138 rules are described.

Table 5.1: **Director of water utility**

Description in brief	Agreed? yes	partly	no
Tasks: a) Check infrastructure proposals of the utility chief engineer. b) Check whether new tarif is needed. c) If necessary, define new price and apply (to city councillor) for approval. d) Inform people (public relations).	☒	☐	☐
Interest: Representation The director of the utility is, according to the legal constraints and the political expectations, obliged to ensure a reliable, daily water service. Correspondingly, he is interested to minimize technical as well as financial risks and to keep the infrastructure in good condition. As he is not directly participating in the utility's potential profit, he has no incentive to minimize the service provided or the infrastructure maintenance. In contrast, he wants to be able to present a technically as well as financially well-maintained utility, which can meet highest technical standards. It is his goal to represent a nationally and even internationally exemplary utility.	☒	☐	☐
Past strategy: Maximize budget Representation can be gained by extending infrastructure with high quality. As the water is not scarce (in this region), there is no need to adopt a water-saving strategy. On the contrary, as much water as possible should be sold in order to gain sufficient income (at given prices). Influence on the political setting can be gained with a maximum budget, as the public utility should not make a profit nor should it make losses. A budget-maximizing strategy features operational flexibility and the possibility to expand infrastructure. In short, this strategy signifies: • Technical security has priority and is extended to a high degree. The financial situation has to cope with the technical development. If necessary, water prices need to be adjusted. Consumers are not consistently influenced towards saving water.	☒	☐	☐
Present Strategy: Minimize expenditures	☒	☐	☐

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Table 5.1: *continued*

Description in brief	Agreed? yes partly no
The infrastructure is more or less built. Now, the main task is maintenance and renewal. Since consumption drops slightly and the overall financial pressure increases, financial considerations gain focus. A good financial situation of the utility is a prerequisite for a good reputation. The technical system must still be functioning perfectly. In short, this strategy means: • Stable financial situation has priority. New projects are only approved if the financial situation is stable. As long as enough capacity is available, water consumption should be maintained high (to produce income).	
Rules: See Appendix B.1.1 on page 125.	

Table 5.2: **Chief engineer of utility**

Description in brief	Agreed? yes partly no
Tasks: a) Check capacity (water works). If necessary, propose adaptation (to director). b) Check pipe net size. If necessary, design expansion. c) Check age of individual pipes. If necessary, replace them. d) Check reservoirs. If necessary, propose adaption (to director). e) Design infrastructure for security, machines, control, etc. f) Determine water use by consumers.	☒ ☐ ☐
Interests: Technical security and perfection The utility chief engineer is responsible for the problem-free technical operation of the infrastructure. The size and the layout of the infrastructure have to meet all possible scenarios, including failure of parts of the system, maintenance of water works, unexpected increase in demand etc. If there would be a shortage of quantity or a deterioration of quality, the chief engineer would be blamed. The main goal of the chief engineer is thus to maintain the operational security. High technical perfection enhances operational security and is also a challenge to every engineer.	☒ ☐ ☐
Past strategy: Worst-case planning	☒ ☐ ☐

continued on next page

Table 5.2: *continued*

Description in brief	Agreed? yes partly no
Risks due to uncertainties (e.g. development of demand, technical problems) are covered by planning for the worst case. Demand is assumed to develop on the upper side of the possible range. Redundancies are designed so that the failure of one large water source could be compensated by the other ones. Reservoir volumes are also designed rather large. In short, this means in the model: • Capacity is designed according to the extrapolation of the past development (long-term) of the annual maximum, daily consumption. • Size of reservoirs must account for nearly an average daily demand. • Pipe mains include built-in redundancy (rings of pipes to shift water from one end of the city to the other, special pipe network for emergencies).	
Present Strategy: Average-case planning The financial situation and the public awareness result in lean planning. If capacity reserves grow too big, this may not be politically acceptable and, in addition, may lead to technical problems. The long-term consumption trend has – in contrast to the strategy of the past – less meaning. The short-term trend becomes more important, which is at the moment slowly decreasing or stable. Downsizing would be taken into consideration if necessary. In short, this strategy means: • Capacity is designed according to the extrapolation of the past development (only short-term) of the annual average, daily consumption. For the estimation of peaks, the average is multiplied with a generous peak factor. • Size of reservoirs must account for clearly less than average daily demand. • Only a small degree of redundancy is built in.	☒ ☐ ☐
Rules: See Appendix B.1.2 on page 127.	

Table 5.3: **Head of finances of utility**

Description in brief	Agreed? yes partly no
Tasks: a) Prepare investment statement. b) Prepare profit and loss statement. c) Prepare balance sheet. d) Make finance plan if required.	☒ ☐ ☐
Interests: Financial stability The utility must present a stable, balanced financial position. This is the main responsibility of the head of finances, as he makes the long-term financial planning.	☒ ☐ ☐

continued on next page

Table 5.3: *continued*

Description in brief	Agreed? yes partly no
Strategy of both past and present: Decrease debt and form financial reserves Major concerns are sufficient income and depreciation as well as debt and book value which are in balance. In particular, financial reserves must be available in order to balance the varying income due to fluctuating water sales. In short, this means in the model: • Conservative financial plans. • High depreciation within the legal limits.	☒ ☐ ☐
Rules: see Appendix B.1.3 on page 134.	

Table 5.4: **Constructing engineering company**

Description in brief	Agreed? yes partly no
Tasks: a) Negotiate size and details of construction job. b) Build new or adapt existing waterworks. c) Build new or adapt existing reservoirs. d) Build new or replace existing pipes. e) Build other infrastructure (buildings, control, information technology, etc.).	☒ ☐ ☐
Interests: Maximize profit within limits of good reputation An engineering firm can only survive if it has the reputation to deliver good quality work at reasonable cost. That's the only way to constantly acquire new projects and thus maintain the size and staff of the firm. But within these boundary conditions, the firm must make a profit: As a basis to grow, to adapt to new developments and to get a good return on invested private capital.	☒ ☐ ☐
Past strategy: Large and spacious solutions	☒ ☐ ☐

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Table 5.4: *continued*

Description in brief	Agreed? yes partly no
As a result of economic growth, competition among engineering companies is relatively small and local. Having a job contract for the construction of infrastructure, more profit can be made if the infrastructure object to be built is large: the payment for the work is proportional to the size of the project. As competition is minor, no price and size reduction happens in the bidding process. Hence, during negotiations for the final adaption of the project, the constructing engineer will argue for spacious solutions in order to provide more security and better flexibility according to engineering principles. As a result, the own income earned on the contract will also be larger. In short, this strategy signifies: • Water works: proposed capacity (by utility) is increased during negotiations. • Reservoirs: proposed volume is increased during negotiations. • Pipes: the proposed diameter is rounded up to the next available one on the market. • Rest: investments are increased during negotiations.	
Present Strategy: Cost effective solutions The competition among engineering firms increased significantly during recent years. As a result, in order to get the job, project cost must be reduced. In short, this strategy means: • Waterworks: proposal for capacity is not increased anymore. Cost is reduced (discount). • Reservoirs: proposal for storage volume is not increased anymore. Cost is reduced (discount). • Pipes: proposed diameter is rounded off to the next common one on the market. Cost is reduced (discount). • Rest: Cost is reduced (discount).	☒ ☐ ☐
Rules: see Appendix B.2 on page 137.	

Table 5.5: **Consumers (made up by knowledge engineer)**

Description in brief	Agreed? yes partly no
Tasks: a) Define average consumption (given from 1908 to 1996, assumption after 1997 for simulations). b) Define maximum consumption (given from 1908 to 1996, assumption after 1997 for simulations). c) Pay initial connection fees.	☒ ☐ ☐

continued on next page

Table 5.5: *continued*

Description in brief	Agreed? yes partly no
d) Pay bill for consumed water (incl. fees). e) Form opinion on quality and cost of service.	
Interests: Good service (no deterioration) The own interests are of prime importance to consumers, since they cannot see the overall effects and interconnections of their behavior on the system. Their goal is to get good services (good water with respect to quantity, quality and tariff) at all times. In particular, their goal on first sight is not to face a deterioration of the offered services compared to the past.	☒ ☐ ☐
Strategy of both past and present: Form and communicate opinion Through public votes and discussions, consumers can point to their needs. Swiss consumers can also turn in an optional referendum. This is critical, as there is no competition among suppliers and consumers cannot choose from whom to buy water. The formation of an opinion is also dependent on the economic pressure on households. In short, this strategy signifies in the model: • Form opinion. When the economic pressure on houses is big, then consumers are sensitive to price changes in subsequent years. Even if the water price is often not directly visible to consumers (renting an appartment), the general discussion will influence consumers nevertheless. When the economic pressure on houses is small, then the consumers are not sensitive to changes of the water price, but of the services. When the services are good (quantity and quality), then consumers are happy. • For simulation (1997 – 2100): in economically-sensitive times, consumers want to reduce the overall cost of their water consumption, especially when the prices have recently risen. As we don't know the price elasticity, we can choose it as a scenario. • For simulation (1997 – 2100): consumers are increasingly ecologically-sensitive. As scenario for the future, they can be influenced by the utility to consume less water in the very few peak hours, resulting in a reduction of the maximum daily peak value in the dry season. As this reduction is speculative, it can again be chosen in scenarios.	☒ ☐ ☐
Rules:see Appendix B.3 on page 142.	

Table 5.6: **City councillor**

Description in brief	Agreed? yes partly no
Tasks: a) Check price proposal. If ok, propose it to parliament for final approval. b) Check construction proposal. If ok, propose it (if needed) to parliament for final approval.	☒ ☐ ☐

continued on next page

Table 5.6: *continued*

Description in brief	Agreed? yes partly no
c) Publish new tariffs.	
Interests: Reliable water supply and good political acceptance The city councillor is politically in charge of the water supply system. He is especially responsible for the organizational structure and the selection of management staff. He decides on his own on smaller and limited investment proposals (projects). Larger construction projects have to be authorized by the parliament. Supervision is the responsibility of the cantonal directorate for buildings ("kantonale Baudirektion"), which also has to authorize the cantonal masterplan of water supply systems ("kantonaler Wasserversorgungsplan, GWP", Wasserwirtschaftsgesetz (1991)). It is hence in the interest of the city councillor that the system works reliably, producing good quality water for the consumers. The service has to be accomplished short-term, but should not prejudice the long-term development. It is a welcome effect if, as a consequence of a reliable water supply system, the political reputation increases.	☒ ☐ ☐
Strategy of both past and present: Focus on security aspects As he is not an expert himself, normally the city councillor supports the requests of the utility managers. As the requests of the managers are generally focussed on security aspects and technically high standard infrastructure, these characteristics coincide with the interest of the city councillor. For requests regarding the building of new infrastructure in times of financial scarcity, the financial state of the utility gets important, as large deficits are in the long run not politically acceptable. This strategy means in the model: • New buildings are approved (and submitted to parliament) if they are urgent or the financial situation (general, not of utility) is good. If neither is the case, then proposals are only approved if the utility is in a sound financial condition. • Regarding new tariffs, the city councillor will accept them and submit them for approval to parliament. According to regulations, the utility has to be financially sustainable in the long run.	☒ ☐ ☐
Rules: see Appendix B.4.1 on page 145.	

Table 5.7: **Member of Parliament**

Description in brief	Agreed? yes partly no
Tasks: a) Decide on tariff increase requests. b) Decide on construction requests. c) Evaluate public opinion.	☒ ☐ ☐

continued on next page

Table 5.7: *continued*

Description in brief	Agreed? yes partly no
(Note: As the members of parliament represent the population, it is assumed in the model that they make the final decisions and that there are no public votes (referendums) on tariffs or on credits for new buildings.	
Interests: Political achievement and re-election Politicians in parliament are the elected representatives of the people. As such, they represent the interests of their voters. Regarding the water supply system, the parliament makes decisions on requests for new buildings (if these investments are larger than a certain amount fixed in regulations) or, if new tariffs are proposed by the city councillor. A compulsary referendum is needed if large investments to be decided on (larger than a certain amount fixed in regulations). Members of parliament also have the option to submit their own proposals. The goal of the members of parliament is to guide the development of the city according to his own, the party's and the voting community's will. The tasks as a member of parliament consist primarily of controling the city councillors (executive) and giving new impulses. However, in order to get re-elected, members of parliament are also obliged to profile themselves and thus to have a good public image.	☒ ☐ ☐
Strategy of both past and present: Focus on public opinion Generally, members of parliament orient themselves towards the public opinion of their voters. If the public is satisfied with the received services, then there is no incentive or need to oppose politically. Members of parliment can also pick up an existing but not completly satisfying situation and put it on the political agenda. In this case, it is important to make political turbulence, in order to gain momentum. In short, this means in the model: • Tariff proposals are accepted either if they are urgent (since required by law) or if the public opinion is positive. • Infrastructure proposals are accepted either if they are urgent or if the public opinion is positive.	☒ ☐ ☐
Rules: see Appendix B.4.2 on page 146.	

5.3 Resulting model

5.3.1 Interactions

The stakeholder interactions revealed during the process of rule evaluation are shown in Fig. 5.6. The arrows reflect the links between stakeholders and domain objects. The dashed arrows represent the water flow between the domain objects and the consumers. All the other interactions between stakeholders and domain objects are needed in order to make this water flow possible.

Only the basic interactions are modeled and depicted in Fig. 5.6. In reality, more interactions may take place, such as those between members of parliament and the director of the engineering company. People know each other, may be members of the same political party, may have common friends etc. Such informal links exist in addition to those depicted. However, they are neglected in the model for reasons of simplicity. Such interactions could be included in a further stage of the model. Further links are also present in that all stakeholders

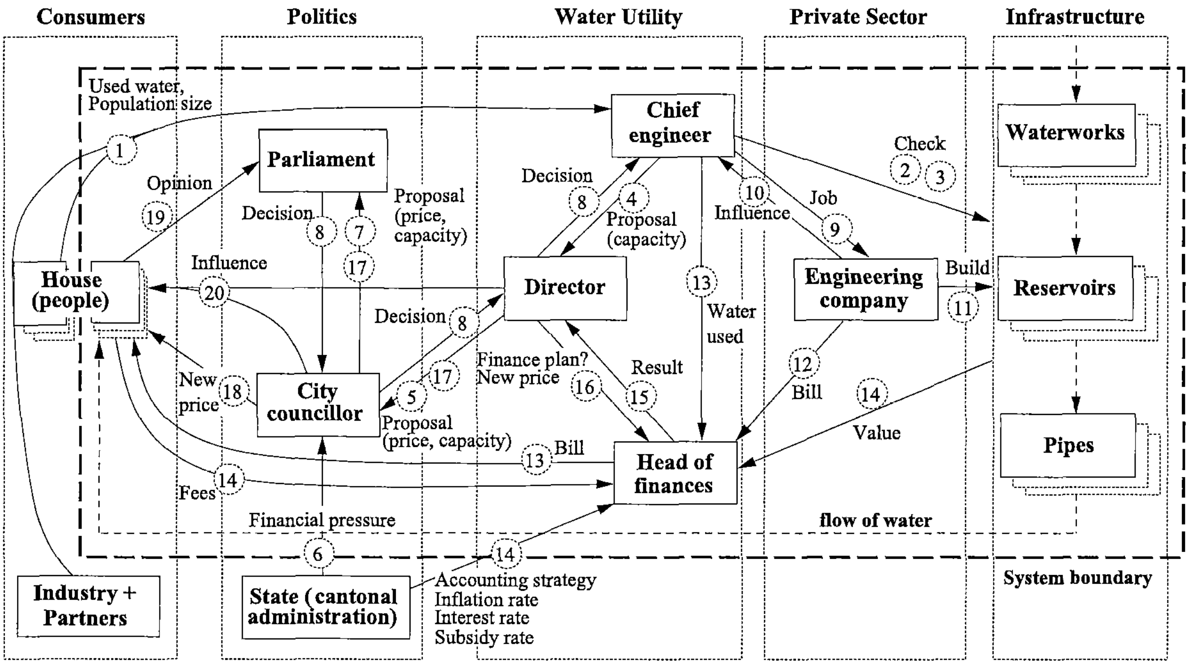

Figure 5.6: Model diagram showing the interactions linking stakeholders and domain objects. The numbers correspond to a sequence of events when capacity increased due to a rise in consumption. The dashed arrows – the water flow - are the basis why all the other arrows are necessary.

shown are consumers at the same time. In principle, therefore, they also see things from a consumer's perspective.

Because the modeled period ranges from 1908 to 1996, the population of the city changes over time (input parameter). Correspondingly, the number of house agents changes in line with population growth. The increased total consumption thus requires an adaptation of waterworks capacity (in number and size), reservoir volumes and the dimensions of the pipe network. The number of pipes depends on the specific pipe length per inhabitant, which is given as an input parameter. The number of links and interactions thus increases as the model grows.

The interactions are described on the basis of an example in the next section.

5.3.2 Sequence of events

The time frame of the following events is one year. The process starts with the houses, which use water and trigger actions by the other stakeholders. The numbers in the following list refer to the numbers in Fig. 5.6.

1. The consumers use water. Consumers are houses (people), industry and partners (neighboring cities). Their annual average and maximum, daily consumption is given by a database.

2. The utility's chief engineer compares the existing capacity of the infrastructure with the new consumption values of the consumers. If peak consumption outstrips existing capacity, a new project to increase capacity needs to be worked out. This is assumed to be the case in this example.

3. At the same time, the utility's chief engineer checks the volume of the reservoirs and the size of the pipe network with respect to population size. Furthermore, the ages of the existing waterworks, reservoirs and pipes are checked. If the ages of these infrastructure elements exceed their expected life span (taking an age distribution into account), they would have to be replaced. This is assumed not to be the case in the events illustrated here.

4. The chief engineer then proposes the required increase in capacity to the director of the utility. The proposal can have different degrees of urgency, depending on recent patterns of consumption and the state of the existing waterworks.

5. The director of the utility considers the financial situation while checking the chief engineer's proposal. If he is in agreement, he submits this proposal to the executive politician (city councillor). This is assumed to be the case in our example. If the director were not to agree, he would inform the chief engineer accordingly and the project would be stopped.

6. The city councillor takes the overall financial situation into account in arriving at his decision. This situation is specified by the state as a boundary condition.

7. If the city councillor supports the need to build new capacity, the proposal is submitted to parliament (in reality, this is only necessary for new projects of large financial dimensions). Otherwise, the proposal would be returned to the director of the utility and the project stopped.

8. The members of parliament have to make the final decision. If they agree according to their rules, then they finally approve the increase of capacity and return their agreement via the city councillor and the director of the utility to the chief engineer. This is assumed to be the case in this example.

9. The utility's chief engineer now allocates a job contract to the construction engineer, assigning him the task of determining the size of the waterworks to be built.

10. The construction engineer, through intensive negotiation with the chief utility's engineer, determines the details of the waterworks to be built, thus adapting its overall size.

11. The construction engineer builds the new waterworks (or adapts an existing one) over several years. The infrastructure built is assigned values such as capacity, net value, life span etc.

12. At the same time, the construction engineer bills the utility's head of finances for the resulting costs.

13. The head of finances in turn bills the consumers for the water delivered to them. To facilitate this process, he receives data on the amount of water the consumers have used from the chief engineer and can bill consumers on the basis of the current water price. Service fees are also charged.

14. The utility's head of finances performs the accounting at the end of the year. From the state he needs data on rates of inflation, interest, subsidies on investments as well as the accounting strategy. The head of finances sums the investments, income (from water sales), expenditures (salaries, materials, interest, depreciation), debt and the value of the infrastructures. He finally calculates the profit or loss of the current year.

15. This result and the utility's financial statements are then submitted to the director of the utility.

16. The director now has to decide whether a new tariff adjustment is necessary on the basis of the values given by the head of finances. In that event, the director decides on a new tariff according to current financial needs and on the basis of a finance plan submitted by the head of finances. This is assumed to be the case in this example.

17. The director then submits this new tariff proposal to the politicians, including the city councillor. He may also consult the members of parliament, since they could initiate a referendum against a tariff increase.

18. If a new tariff is agreed, it is the job of the city councillor to inform the consumers about it.

19. The consumers, confronted with a new tariff, form an opinion about the water service they are receiving. This opinion is submitted to the members of parliament in its turn and will influence their next decision on a capacity or price proposal.

20. In the model scenarios of the future (starting in 1997 and ending in 2100), the director of the utility and the city counselor have the option of influencing the consumers. Thus the latter could be influenced to adopt a water-saving attitude, in particular to reduce their daily consumption peaks. For scenarios which include price-elastic demand, the change in tariff may influence consumption.

As can be seen, many decisions are made within a single year. Note that sequences of events similar to those shown in the example given above are repeated each year.

5.3.3 Implementation

The model was developed using the JAVA modeling language. The "Java WorkShop 2.0" from SUN Microsystems was used as the development environment. The model structure, the class diagram and an example of interaction diagrams of the model can be found in Appendix C on page 157.

Fig. 5.7 and Fig. 5.8 give an impression of the graphical user interface (GUI). The model is not designed to be put on the World-Wide Web or for potential users to work with independently. Its use must be part of the overall participatory process. This is a precondition for achieving positive results and eliminating misunderstandings. The GUI is therefore simple and contains no animation features, but it is sophisticated enough to demonstrate the computer model to the stakeholders. It is split vertically into five horizontal parts. The menu bar at the top allows preset simulation scenarios to be loaded (*File*, to manipulate a tailored *Simulation* (start, stop, reset), to start the sensitivity analysis with the *MonteCarlo* simulator, and to view the parameters of the *Stakeholders* (Fig. 5.7). The navigation buttons allow the user to navigate through the model in order to view the beliefs or states of stakeholders or domain objects. The beliefs are displayed in the input field. The model output (state of agents and emergent properties) is displayed in the reserved space of the output field. Input and output values are thus clearly separated. The bottom section of the GUI contains the running time (year, month) and displays key output variables such as the number of pipes, the actual peak demand, the actual capacity size etc.

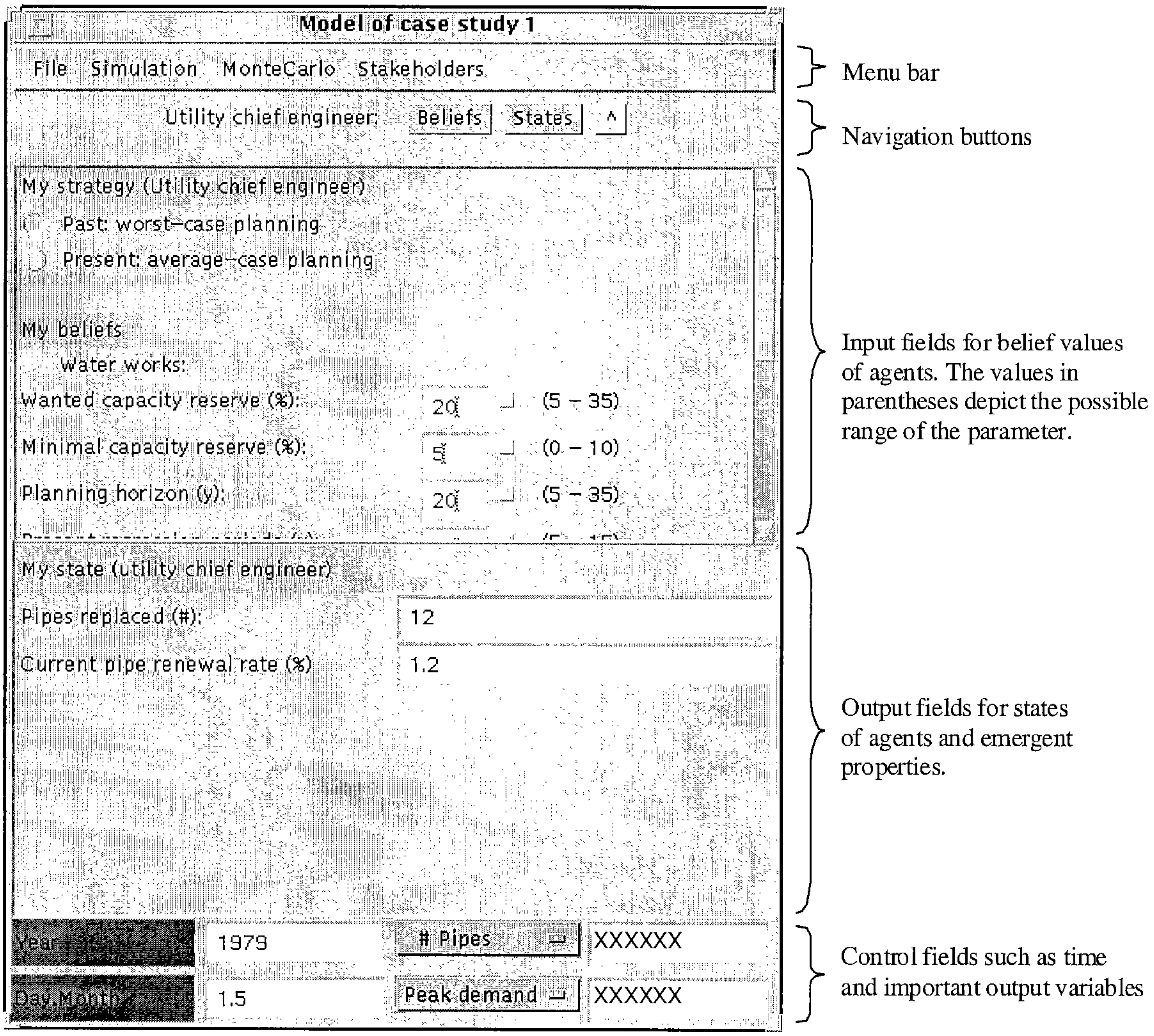

Figure 5.7: *Graphical user interface of the model. The interface is split into five sections which are kept separated no matter how the user navigates within the model.*

5.4 Results and Validation

Despite the abundance of interactions, boundary conditions and environmental as well as political inter-dependencies, these rather simple model rules can replicate the general development of both capacity and cost-related parameters in a satisfactory way. The following graphs show the development of the modeled variables over time according to the evaluated rules (Appendix B). This development can be compared with the observable development of the examined utility.

First, the system capacity is considered. This (Fig. 5.9) represents the amount of water which can be delivered to the consumers per day. It depends predominantly on the size of the waterworks (including pumping stations) and the diameters of the pipe mains. A comparison of modeled and observed capacity development shows that the patterns of the two lines generally match. However, the temptation to compare the details of the two curves should be avoided. As the rules are fundamental, only the trend and characteristic pattern of the two lines are relevant.

The outcome of the modeled capacity depends mainly on the rules: first, if rising consump-

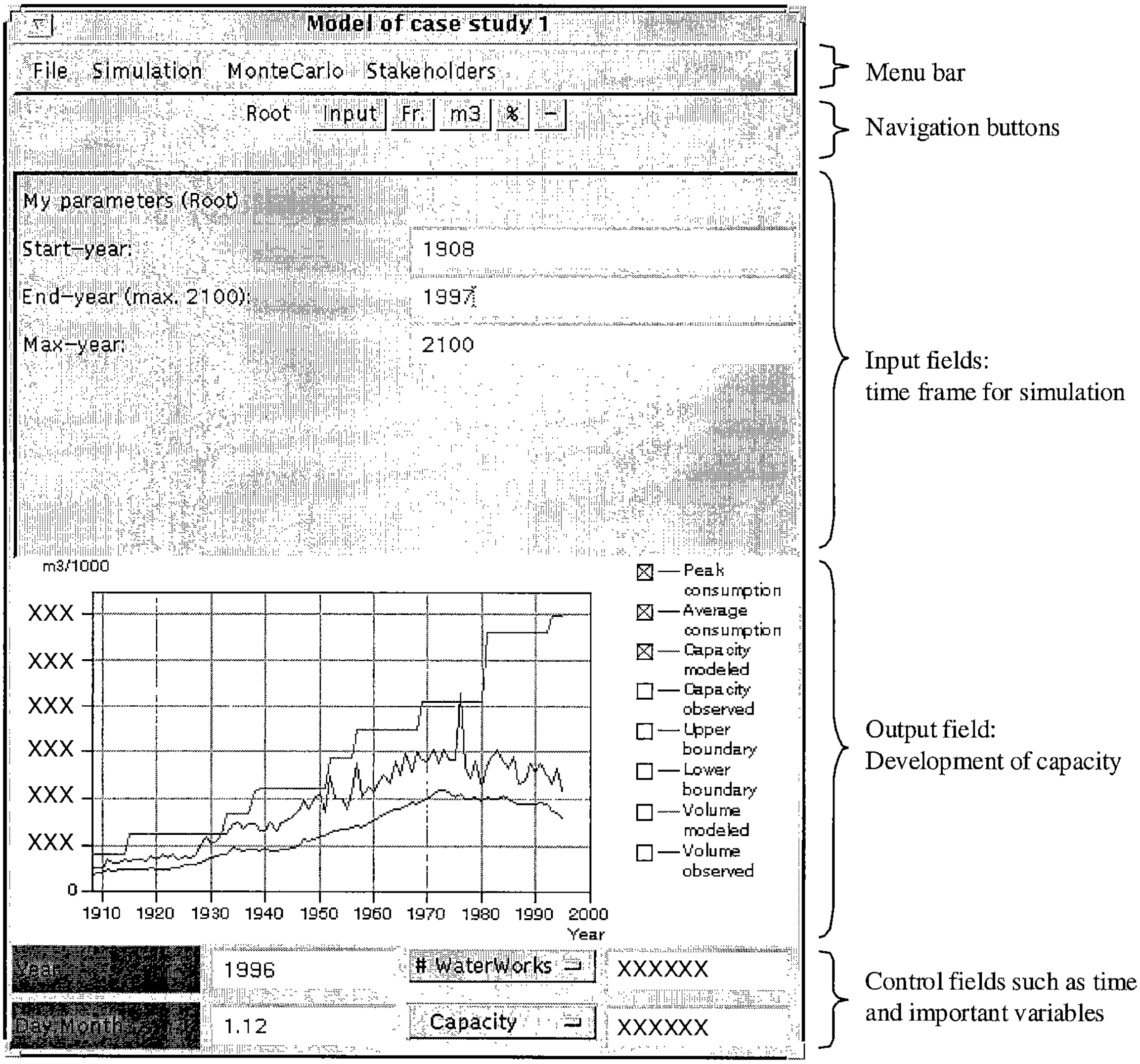

Figure 5.8: *Graphical user interface of the model. The input parameters (e.g. time frame for simulation) are clearly separated from the output variables (e.g. development of capacity).*

tion approaches current capacity, the utility's chief engineer starts to plan an expansion of existing capacity. Since the planning and construction of new capacity takes time, the actual capacity increase is delayed (example of this situation in Fig. 5.9: capacity increase in 1980 after a peak in 1976). Secondly, a capacity increase may become necessary if the age of an existing waterworks exceeds its expected life span. In this case, the obsolescent waterworks needs to be renewed and its size may simultaneously be increased due to the design rules (an example of this situation in Fig. 5.9: modeled capacity increase in 1993). The rules of other stakeholders (director, politicians) could hinder the capacity increase as they have to approve the proposal submitted by the chief engineer of the utility.

The modeled development of the total reservoir volume (Fig. 5.10) does not match the development of the observed reservoir volume at all well. Obviously, the rules are still neither good enough nor complete enough to reflect the observed pattern sufficiently well. In the model, the rules for building more reservoir volume depend primarily on the development of average consumption. An aspect which was not considered is that reservoirs were only built as a "second priority" after the completion of the waterworks. Since the utility is constantly

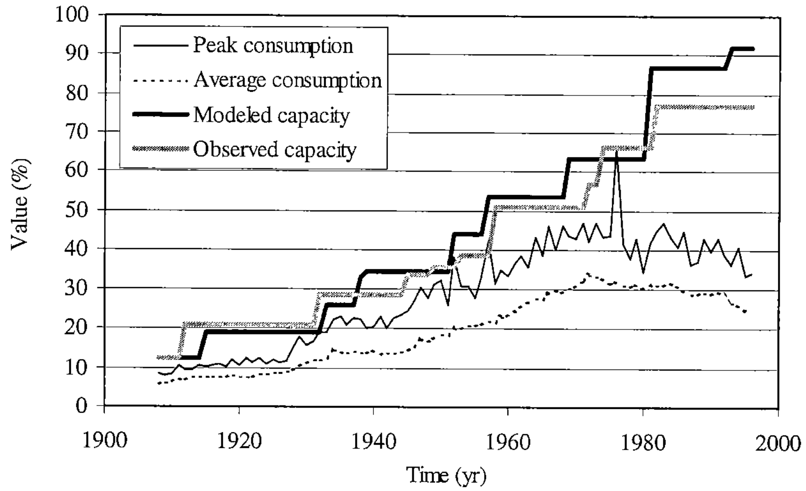

Figure 5.9: *Comparison of modeled with observed system capacity. Although the units of the values on the vertical scale would in reality be m^3/d, they are shown in relative terms, ranging from 0 to 100%.*

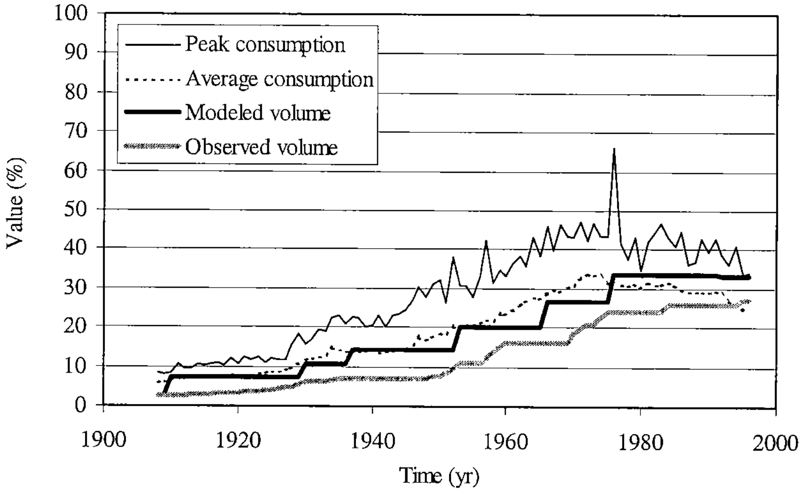

Figure 5.10: *Comparison of modeled and observed reservoir volumes. Although the units of the values of the vertical scale would in reality be m^3/d, they are shown in relative terms ranging from 0 to 100%.*

under pressure to increase the system capacity (waterworks), no resources were left over for the reservoirs. In addition, reservoirs can be substituted by pumping capacity. Clearly, the model rules could be improved after discussions with the stakeholders. This was deliberately not done in order to demonstrate both good (waterworks) and poor (reservoirs) matching rules. Since reservoirs have only a minor influence on the finances of the utility, this deficit in the model will not have a significant effect on the subsequent calculations of the financial parameters.

As the population of the city grows, the pipe network needs to be expanded and adapted. Some pipes also need to be replaced as their age exceeds their expected life span. On the whole, modeled and observed pipes can be compared by depicting some of their attributes at a given time. Fig. 5.11 shows the age distribution in 1996 (end of the modeled period). While the younger age categories exhibit a similar pattern, the model does not include any pipes which are very old. There are three possible reasons for these differences: Firstly, there

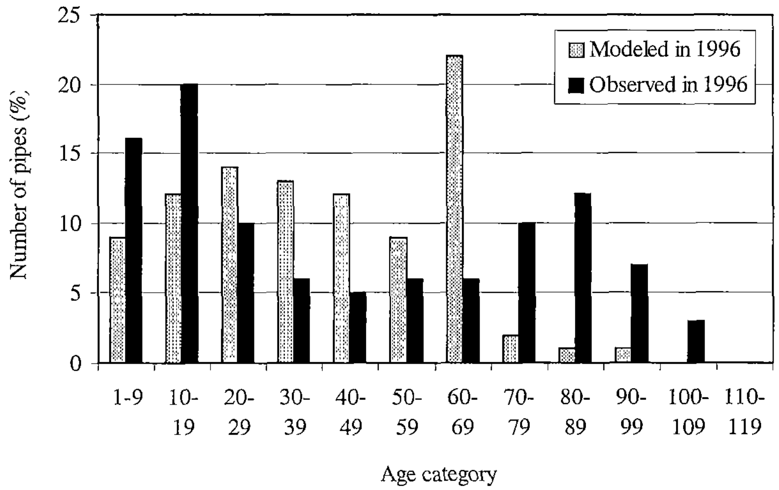

Figure 5.11: Distribution of pipe age in the year 1996. The percentage of pipes in the model and reality for each age category is only partly comparable. In general, the modeled pipes are too young (see text).

are no rules in the model such as "World War 2". Clearly, during the World War of 50 to 60 years ago, the utility did not build lots of new pipes and expand its network. Only minimum investments were made due to the limited resources available - both human and in terms of materials. Thus the model overestimates the construction of new pipes during this period. Secondly, it does not account correctly for networks of neighboring municipalities merging into the utility's network. Hence, when neighboring municipalities were included, the population increased stepwise and, as a result, new pipes were built. In reality, however, the pipes had already been built by the former utility (of the old municipality) so that the age distribution is shifted towards the left and the model showed too many young pipes. And thirdly, the average life expectancy of model pipes built at the turn of the century is assumed to be 80 years with a standard deviation of 10 years. As a result, no pipes in the model are older than about 100 years. In reality, however, some pipes are extremely resistant and are older than expected (over a century). Overall, the pipe distribution of the model in 1996 only partially matches the observed distribution. A further improvement would have to take the historical development more fully into account.

The well-matched diameter distribution of modeled and observed pipe mains is an artifact (Fig. 5.12). In the model, when a new pipe is built, the diameter is assigned by relating the diameter distribution of the relevant year (e.g. 1940) to those of 1908 and 1996. This mechanism (see Appendix B.6.3 on page 154)for determining new model diameters is arranged so that the distribution resulting at the end of the modeled period (1996) is similar to the observed one. A more realistic design mechanism would have to take a geographical information system (GIS) into account.

Annual investments are needed to pay for all these construction efforts. Their modeled nominal development is shown and compared with the nominal investments actually realized (Fig. 5.13). At first sight, the annual amounts of the modeled and observed investments vary considerably. The modeled development shows many investment peaks which are not observed in reality. There are many reasons for these differences. As seen above, the modeled development of waterworks, reservoirs and pipes exhibits some differences when compared with the observed data (time of construction and size). These deviations are also passed on to the investments. Particularly great differences in modeled and observed investments can

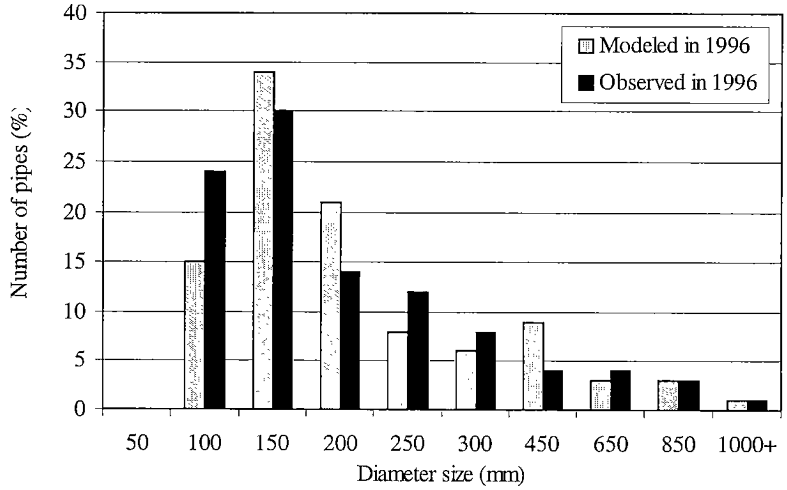

Figure 5.12: *Distribution of pipe diameters in 1996. Although the distributions in the model and reality are comparable, they are an artifact due to the calculation mode.*

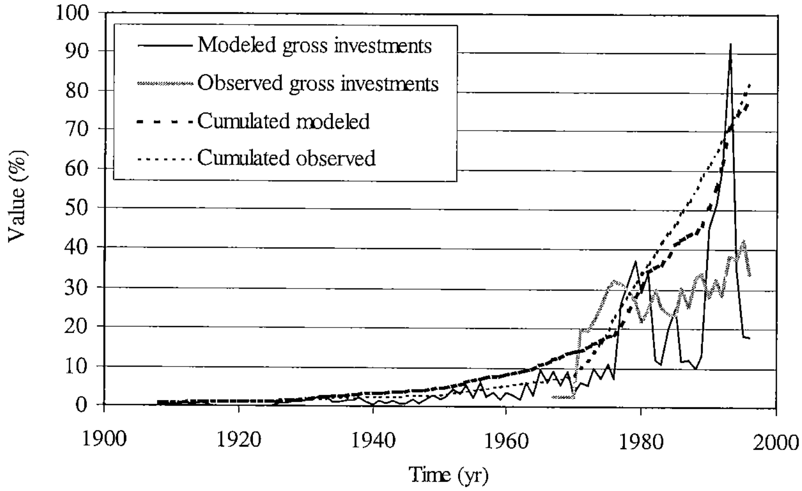

Figure 5.13: *Modeled, observed and cumulative gross investments (nominal). The vertical scale is relative, ranging from 0 to 100%.*

be seen around the year 1970. Whereas in reality investments picked up in 1970, the modeled investments showed a time lag of about five years. One reason for this is that the model does not account for any "discreet" events which fail to obey the overall tendency. Thus an accident (chemical spill) which occurred in 1967 led to the political will to invest further in the utility's waterworks. A second main difference is seen around 1990 when the modeled investments show a sharp peak. This is due to the lack of a way of equalizing investments. In reality, investments are planned so that they are of similar size in subsequent years.

Although the occurrence of modeled investments varies with time when compared with the reality, the cumulative sum of these investments roughly corresponds to the actual sum (Fig. 5.13). The differences in cumulative investments in the years 1950 to 1970 are mainly a result of the surplus pipes built in the model during this period (as discussed above).

The book value of the infrastructure, debt and depreciation are related to the investments

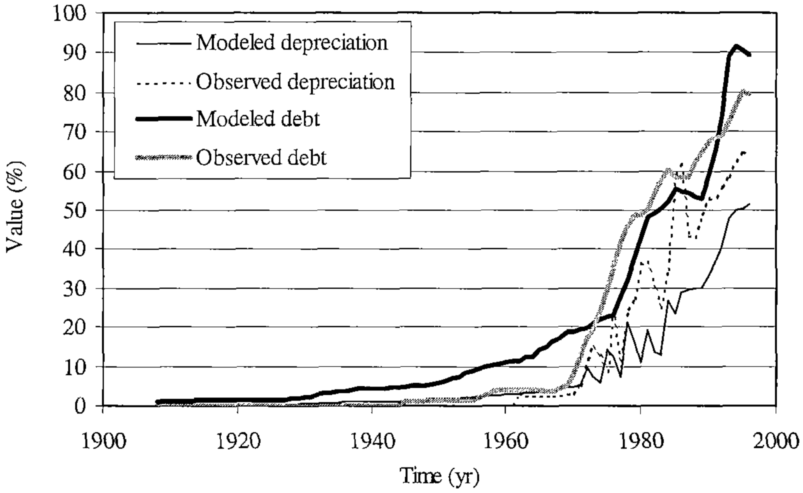

Figure 5.14: *Modeled and observed depreciation and debt. The debt is approximately equal to the book value of the infrastructure.*

(Fig. 5.14). Because investments exceeded depreciations in the past, there is a constant increase in book value and at the same time in debt (approximately equal to the book value). A comparison of modeled and observed debt shows that both values follow the same trend. However, any investment errors in the model are also noticeable in the debt curve. Modeled and observed depreciations deviate by around 20%. This is the result of the model rules, which are designed to be simple and underestimate the net value of the individual waterworks. Since this value represents the basis for the depreciation, the latter becomes too small. Clearly, the rules here offer potential for improvement.

In order to calculate a price for a unit of water, further costs need to be calculated. These include the costs accruing for salaries, general expenses (material, energy, chemicals etc.) and interest. Both salary and general costs are calculated as a function of the amount of water the utility can deliver (capacity). The interest is dependent on debt and on the interest rate, which is an input parameter (see section 5.1.4 on page 43). The modeled development of these three curves is not shown but matches the pattern of the observed development.

Accounting principles are applied and a water tariff is calculated on the basis of income (earnings from delivered water and fees) and expenses (salaries, general expenses, interest, depreciation). Fig. 5.15 shows the modeled tariff per m^3 of water compared with the observed tariff. General agreement of the patterns of both curves can be observed. The deviations of the modeled and observed curves of the variables forming the price obviously cancel each other out. The observed nominal development of the price can also be compared with the actual development of the modeled price (in real terms). Such a curve is given after 1982, taking inflation of living costs into account (index of consumer prices). The observed rise in prices exceeded the development of inflation.

The overall cost to consumers is more than just this consumption-dependent charge for the water used. They also have to pay annual service fees (not shown in the figure). The level of income to the utility resulting from these fees is 40% and they increase in proportion to the water fee.

The development of the overall depreciation rate (Fig. 5.16) reflects the different accounting periods. Before 1972, the deprecation rate was fixed at about 2%. This rule changed between 1972 and 1985. Profits could be used to temporarily enhance the rate of depreciation, so that a fluctuating rate resulted. A balance account was introduced as of 1986 after the corresponding

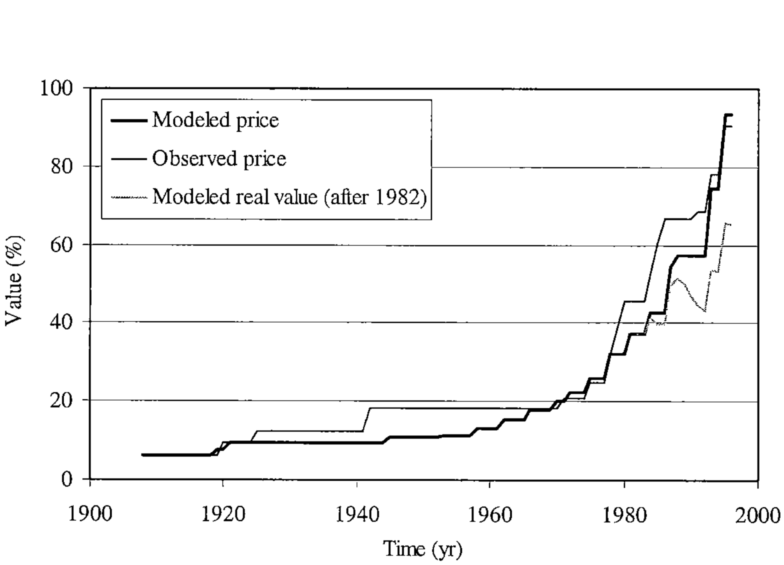

Figure 5.15: *Comparing modeled and observed prices for a unit of water, excluding the service fees, which provide 40% of the total income of the utility as against the 60% coming from the water fees. The modeled real value takes inflation into account (after 1982).*

regulations were changed by the state (the public utility must comply with the accounting rules of the state). The profit could no longer be used to increase the rate of depreciation and any losses could not be reduced by a minimized rate. The deprecation rate was set by the state at 4%.

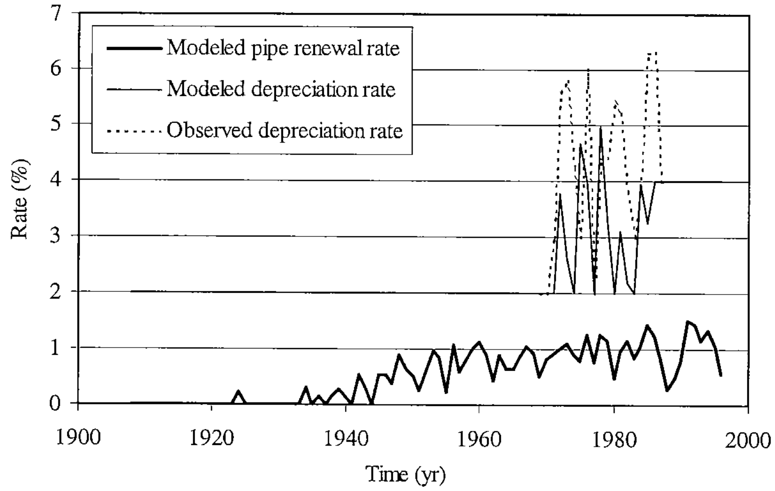

Figure 5.16: *Development of deprecation rates and rate of pipe replacement (maximum 1.5%).*

The replacement rate of aged pipes is also calculated in the model. It was determined to be approximately 1.5% in recent years, which corresponds to the observed replacement rate of around 1.5 to 2%. This modeled renewal rate is high enough to replace all pipes well before they reach their assumed life span. In reality, one main pipe breaks per day. However, this number cannot be reproduced by the model because the modeled chief engineer cannot be surprised by a pipe break as he knows the expected life span of all the pipes in the model and can replace them in time.

5.5 Model uncertainty

In order to gain more confidence in the modeled results, a sensitivity analysis was performed with respect to the model parameters. A full sensitivity analysis would include a comprehensive search of the parameter space. The input parameters would have to be varied simultaneously and all the output variables observed. However, a limited form of the analysis was performed as outlined in chapter 4. Uncertainties with respect to the model structure, the system boundary or the input data were also not explored because of limited time resources.

An overview of the parameters representing the beliefs of the stakeholders is given in Appendix D on page 161. In total, 42 parameters influence the outcome of the model results. This large number suggests that the model might be over-parameterized. The classical principles of modeling dictate that a parameter must be eliminated from the model if it does not influence the latter's outcome significantly. However, the goal of the model presented here is quite different: many parameters are included in it not because a parameter-estimation procedure suggested their relevance but because the stakeholders' have incorporated them in the rules. They are consequently used to complete the picture of the stakeholders' mental model. So the results must be regarded as data generated from rules with many parameters rather than as an attempt to mimic reality with as few parameters as possible. This distinction between the present dynamic rule-based expert system and other classical models should be kept in mind.

Monte Carlo simulations were performed as a first way of testing the influence of different parameters on the outcome of the model. The output variable considered is the overall system capacity. 27 parameters were selected and were changed randomly (Gaussian randomizer) within a given range from one simulation run to the next. The parameters considered are indicated in Appendix D by a tick mark in the "MC" column. The Appendix also gives the range of each parameter. The model was run with 30 simulations, each from beginning (1908) to the end (1996) of the modeled period (Fig. 5.17). More simulation runs were performed but they are not shown in the figure because they would render it unreadable (too many curves). However, the number of runs required by a detailed Monte Carlo procedure was not calculated specifically (see e.g. Morgan and Henrion (1990)). The cluster of curves shown in the figure gives an optical impression of the range of output values. The figure indicates that no matter which parameter settings are chosen within the given range, the output variables remain within a narrow band. The trend of this development matches the pattern shown by the observed variable. The only larger deviation is at the end of the modeled period, when the observed values are smaller than the modeled ones.

A second way of testing the model's uncertainty is to explore the effect of individual parameters on certain output variables. Fig. 5.18 shows the parameter "planning horizon for waterworks" when designing a new waterworks. This parameter was altered within a range of 5 to 35 years (Fig. 5.18). The value evaluated on the basis of the rule catalog is 20 years.

The left figure (5.18) visualizes the range of effects on the capacity achieved by varying the parameter. The differences between the 30 runs ([parameter from 5 to 35) are not very great. All the capacity developments in the various runs follow the same pattern, eventually going in the same direction. The difference is that in one extreme case (planning horizon 35 years) extensive capacity reserve is created, while in the other extreme case (planning horizon 5 years) it is kept to a minimum. Nevertheless, all the runs can provide sufficient capacity at nearly all times. The figure on the right shows the calculated deviations of each run. According to equation 4.1 on page 38, the deviations are cumulated over the whole simulation period. It can be seen that a planning horizon around the evaluated default value of 20 years seems to match the observed development better than the extreme values. However, only the differences

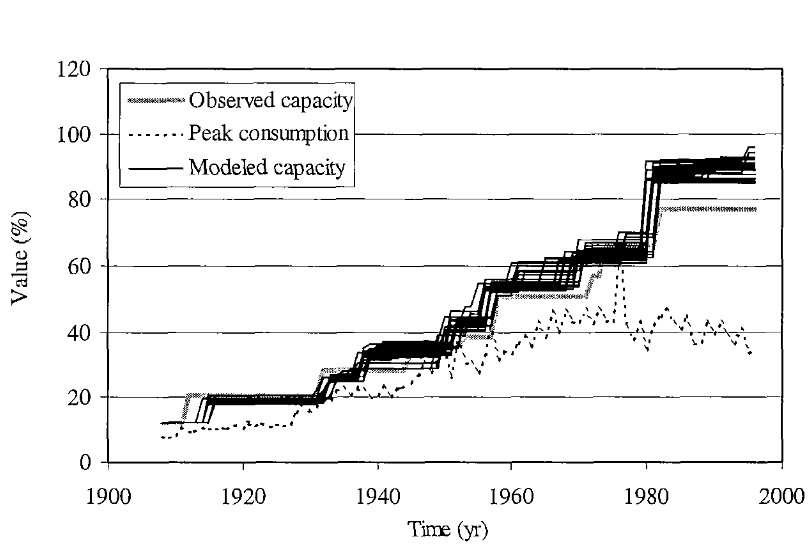

Figure 5.17: *The result of 30 simulation runs in which 27 parameters are changed randomly within their range. The capacity is shown as an output variable. The pattern is similar in all runs.*

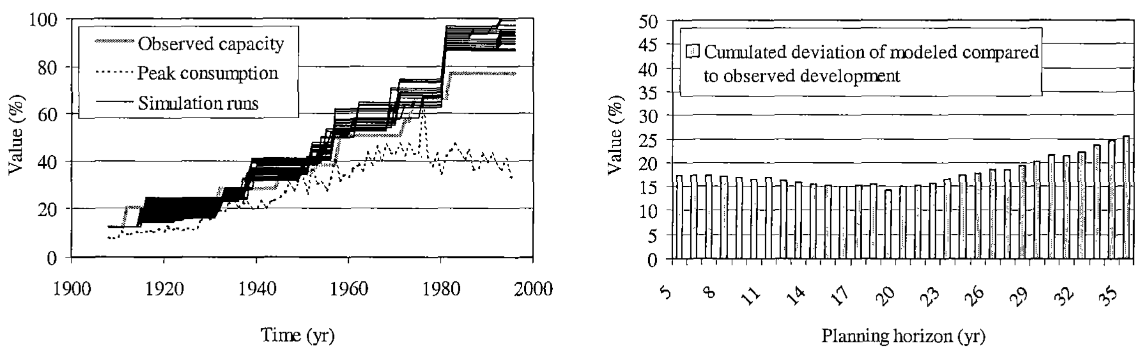

Figure 5.18: *Changing the parameter of the "planning horizon" for waterworks. Range from 5 to 35 years, the average default value according to the rule catalog is 20 years. Left: the vertical scale is relative, ranging from 0 to 100%. Right: The vertical scale shows the relative deviation of the simulation run from the observed development.*

between the extreme values of the upper range (e.g. greater than 30 years) and the default value (20 years) are really considerable.

Changes in the parameter "planning horizon" may also affect other output variables. As the construction of new capacity needs investments, their diverse expansion may influence the development of the water tariffs. Fig. 5.19, shows the effect of changing the parameter on the water price. This effect is clearly minimal. The duration of the construction flattens the effect and other investments (e.g. pipes, reservoirs, rest) also influence the development of the water price.

Overall, the simulations show that the output variables (capacity and price are shown here as examples) are not very sensitive to the input parameter "planning horizon". Another parameter was chosen as a comparison for performing sensitivity runs. The parameter defined as the "wanted capacity reserve" of the utility's chief engineer describes the threshold (20%) when a new design procedure for new capacity is triggered (Fig. 5.20).

As in the previous example, Fig. 5.20, left, gives an optical impression of the range of

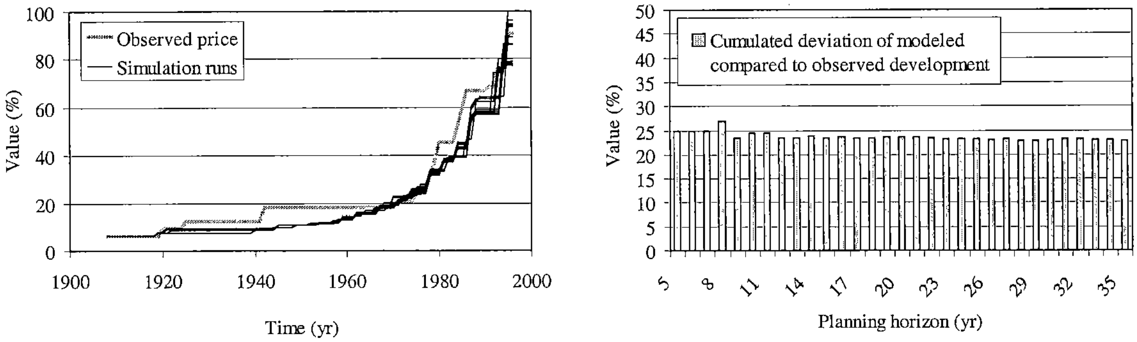

Figure 5.19: *Effect on price when changing the parameter of the "planning horizon" for waterworks. The average default value according to the rule catalog is 20 years. Left: the vertical scale is relative, ranging from 0 to 100%. Right: The vertical scale shows the relative deviation of the simulation run from the observed development.*

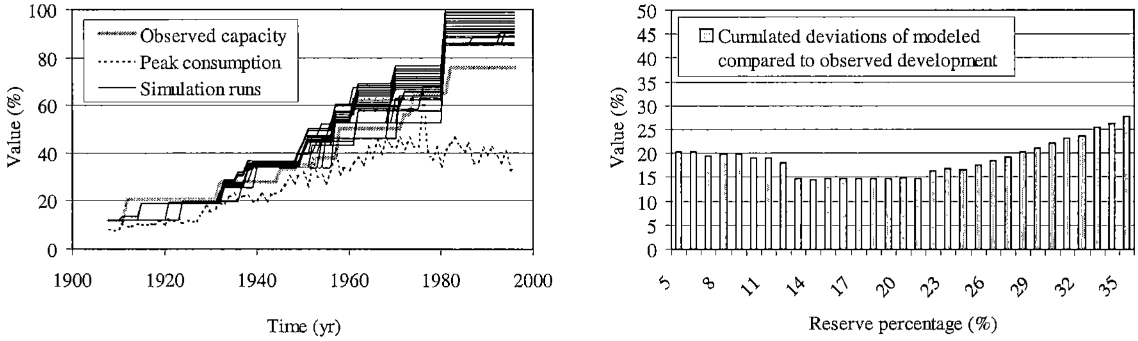

Figure 5.20: *Sensitivity of capacity to the parameter "wanted reserve percentage". The default value according to the rule catalog is 20%. Left: the vertical scale is relative, ranging from 0 to 100%. Right: The vertical scale shows the relative deviation of the simulation run from the observed development.*

possible capacity developments. The right-hand side indicates the cumulated deviation for each run. Again, the default value according to the rule catalog of 20% yields a minimum cumulated deviation. As for the previous parameter, no really significant influences of the parameter range can be found here either.

A further parameter examined is the percentage by which the utility's head of finances increases the expected turnover in order to define the new water price (Fig. 5.21). The range is within the 10% to 20% band, taking 15% as the default value (see Appendix B). As before, the comparison of the resulting price with actual developments in the figure indicates that the differences in value have no significant effect.

A major problem in such simulation runs is that only two variables are observed (capacity and price). But there may also be effects on further variables, especially those which are cumulated over the modeled period. This was illustrated by performing simulation runs with the parameter of "maintenance percentage" (Fig. 5.22). The percentage of investments requiring annual maintenance and updates of existing infrastructures is assumed to be 3% in the model as a default value. According to the figure on the right, one might assume that the value at the upper end, namely 5%, will turn out to be better. If the effects of this parameter on cumulated values such as investments or debt are also considered, it can be seen that the effect of the pa-

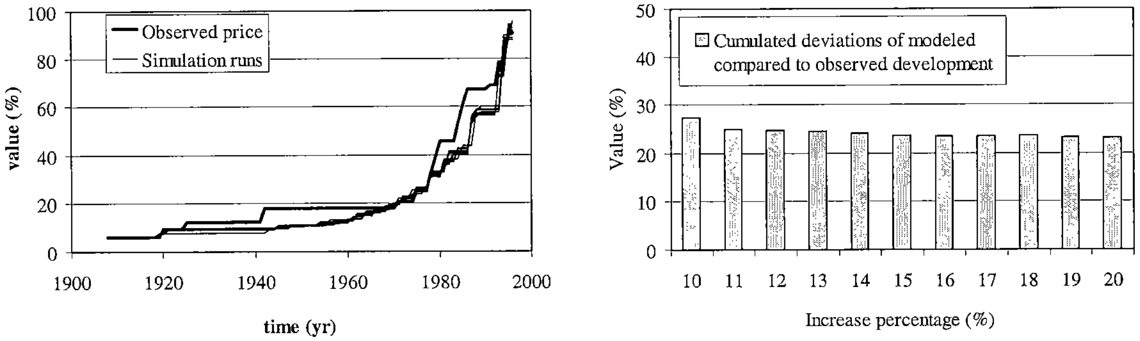

Figure 5.21: The parameter "income by" gives the amount by which the existing turnover is increased in order to determine a new water price (15% as default value). Left: the vertical scale is relative, ranging from 0 to 100%. Right: The vertical scale shows the relative deviation of the simulation run from the observed development.

rameter change is substantial. Fig. 5.23 shows the cumulated investments and compares them to the observed ones. The development of debt is also shown. The maintenance percentage was selected at the lower end (1%) as a basis for the left figure, while the upper end (5%) was selected for the right figure. In the left figure, both cumulated investments and debt are too low compared with the reality, while in the right figure both variables are too high. A medium parameter value (3%) still appears to be the best value.

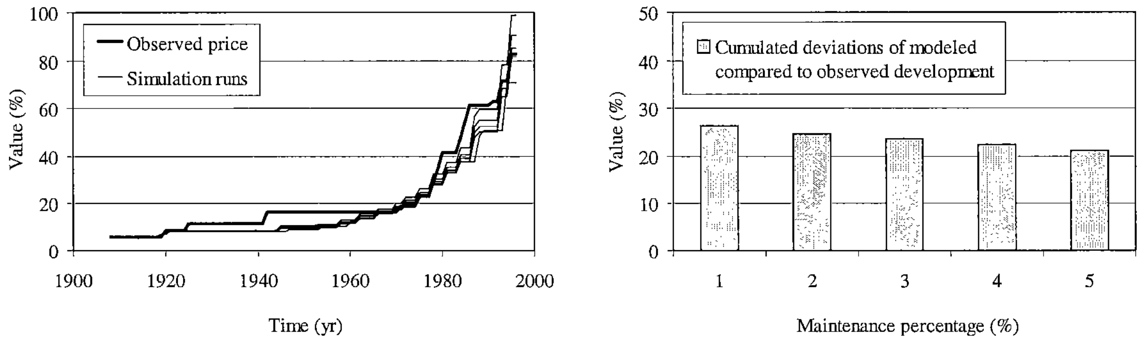

Figure 5.22: Changing the parameter "maintenance percentage", describing the annual investments in updates of existing technology plus minor repair and maintenance of existing infrastructure. Left: the vertical scale is relative, ranging from 0 to 100%. Right: The vertical scale shows the relative deviation of the simulation run from the observed development.

Two conclusions can be drawn from these sensitivity tests.

- The sensitivity tests give a general indication of the range of effects by changing the parameters. However, a significant increase in the knowledge of and confidence in the model cannot be gained by performing more sensitivity runs of this kind. The sensitivity simulations showed that the parameter values given in the rule catalog are good average values which appear to be reasonable. The model fit cannot be improved by adjusting individual parameters.
- No particular parameter of the individual rules dominates the whole system. The development of the system is not dominated by a single design parameter (assumed to be

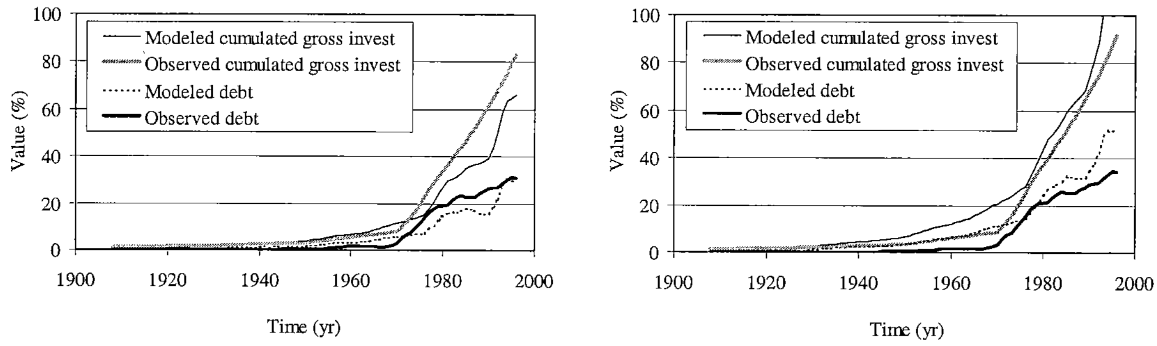

Figure 5.23: Comparing cumulative output variables such as debt or cumulated gross investments when considering two different values of the input parameter of "maintenance percentage" at the opposite extremes of the range. Left: 1%. Right: 5%.

within a reasonable range). The stakeholders' strategy and rules may be more important than individual parameters. In addition, the development of consumption, especially its peaks, may have a considerable effect on how the infrastructure develops.

These conclusions will be further clarified by the simulations of specific scenarios described in the next chapter. Individual rules will be changed and specific scenarios of consumption development assumed.

Chapter 6

Simulation scenarios (case study)

The performance of three different strategies (sets of rules) is tested in the following scenarios. The strategies are initially tested against abstract demand patterns. Secondly, they are applied in retrospect to the observed development of consumption in the past. Thirdly, a selection of scenarios of the future development of the utility is described. Preference is given to a strategy which aims at small capacity reserves and is based on consistent demand-side management.

6.1 Overview

Simulation is used to generate the output of a model for given values of the parameters, inputs and initial values (Carstensen et al., 1997).

The *benefits* of running simulations are potentially twofold: firstly, a simulation helps to increase our understanding of the processes governing the modeled system. By performing "what – if" simulations, the user can explore the behavior of the model, thus enhancing his insight into the modeled system. Secondly, simulation can be used to predict future developments of the modeled system. The assumption of future developments of input parameters yields a forecast of how the system may behave.

The *problems* occurring in conjunction with simulations are also twofold as a first approximation. The first problem relates to what is being modeled. If the model is ill-defined, depicts the wrong interactions and fails to focus on the relevant stakeholders, the simulations will be misleading. The second problem relates to the complexity of the model. If it is too simple and does not cover the complex nature of reality well enough, the simulations again tend to mislead one's intuition. These problems are specifically relevant to the model and simulations of this project. Since the modeled system is poorly understood, how can one be certain whether the model is well or ill-defined and whether it is complex enough? A discussion of the simulation results with the same domain experts who helped build the model is therefore a most important step. Their intuition must be compared with the impression given by the simulation results. Possible differences must be discussed.

Three types of scenario simulations are performed in this chapter. The development of consumption represents the basic input in all of them.

Firstly, the goal is to explore how different strategies perform with respect to various consumption patterns. Only the variable capacity is observed. All other types of variable are not considered for reasons of simplicity. The simulations run over a period of about 150 years so that the evolving pattern can be seen. They all start with the initial conditions of 1908.

Secondly, scenarios are executed with the development of consumption in the past (1908 – 1996). The performance of different strategies is again evaluated.

The third type of simulation starts with the modeled situation of 1996 as the initial condition. Scenarios of further consumption development are then assumed. The performance of the existing strategies can be compared with that of alternatives. Since the model contains many variables, it is not possible to depict the development of all of them for each simulation. Therefore, the same variables are always shown in order to compare them between scenarios. These main variables are production capacity, the development of investments, water price and debt.

6.2 Definition of strategies

Three alternative strategies are tested (Tab. 6.1).

Table 6.1: Characteristics of the three alternative strategies.

Characteristics	Strategy A ("past")	Strategy B ("present–")	Strategy C ("present+")
Security wanted	High	Low	Low
Dataperiod for trend analyses	Long	Short	Short
Consistent demand side management	No	No	Yes (peaks)
As result, elastic demand	No	No	Yes
Competition	No	Yes	Yes

Strategy A represents the strategy of the past according to the rule catalog. It is characterized by high requirements on supply security. The targeted capacity reserve is thus relatively large (20%). A reduction of capacity in the event of a decline in consumption is not considered. In addition, the chief engineer of the utility takes all consumption data from 1908 onwards into account in his plans for the regression and extrapolation of new capacity. Management concepts aiming to influence consumers and reduce demand peaks are excluded and consumption is therefore assumed to be price-inelastic. Since no strong competition between the competing construction companies is targeted, prices are relatively high: costs are increased by 20% over the normal price.

Strategy B is based on the rules known as the "present strategy" from the rule catalog. The security demands of the utility are lower, hence less capacity reserve is required (5%). Only 10 years are considered for the regression of past consumption data (see Rule Catalog in Appendix B). Capacity could be reduced if consumption decreased. According to this strategy, the utility's director can influence the consumers if required. However, such demand-side management attempts are not consistently pushed through, so consumers do not respond to such influence. Strong competition between engineering contractors is assumed, and this leads to reduced prices for construction jobs. Costs are thus reduced by 20% compared with the "normal price". Before, costs were increased by 20%. The total reduction is thus assumed to be 33%.

Strategy C is also based on the "present rules" from the rule catalog. It is also pro-active: it attempts to guide the development of consumption peaks consistently whenever existing capacity reserves become small. It is accordingly assumed that consumers react to influence from the utility. This influence is assumed to result in a 30% decrease of the peak/average ratio. Moreover, it must also be assumed that consumers – now aware of consumption and prices - will react to price changes. A change in the water tariff will consequently influence consumption. A price elasticity of -0.2 is assumed. This means that if the price changes by 10%, consumption will change by 2% in the opposite direction. This price sensitivity influences average demand, but not the peak/average ratio.

The relevant and changing parameters are summarized in Tab. 6.2. All other parameters are taken from the default values given in the list of parameters (see Appendix D).

Table 6.2: Parameter settings for the three alternative strategies. For all other parameters, the default values are taken (see Appendix D). See text for details.

Stakeholder	Involved parameters	Scenario A ("past")	Scenario B ("present–")	Scenario C ("present+")
Consumers	Price elasticity	0.0	0.0	-0.2
	Reduced peaks if influenced	0%	0%	30%
Utility director	Strategy	past	present	present
	Influence on consumers	no	partly	yes
Utility chief engineer	Strategy	past	present	present
	Capacity reserves	20%	5%	5%
	Data for regression	since 1908	last 10 yrs	last 10 yrs
Constructing engineer	Strategy	past	present	present
	Volume adaption	10%	0%	0%
	Cost adaption	20%	-20%	-20%

6.3 Simulations with patterns

6.3.1 Definition of patterns

Four consumption patterns are considered for checking the performance of the strategies with respect to production capacity (Fig. 6.1). These patterns reflect possible consumption developments which have occurred at some time in the past. In each of the four diagrams, the average daily consumption trend over a year is represented by the lower line. This average provides the basis for the maximum daily consumption over a year(upper line). It is calculated by multiplying the average demand by a factor of 1.3. This figure represents an average peak/average factor. In the past, these factors varied between 1.2 and 1.7 over the years, with extreme values rising up to 1.8 (in 1976). However, extreme events are excluded from the modeled patterns in order to represent a general situation.

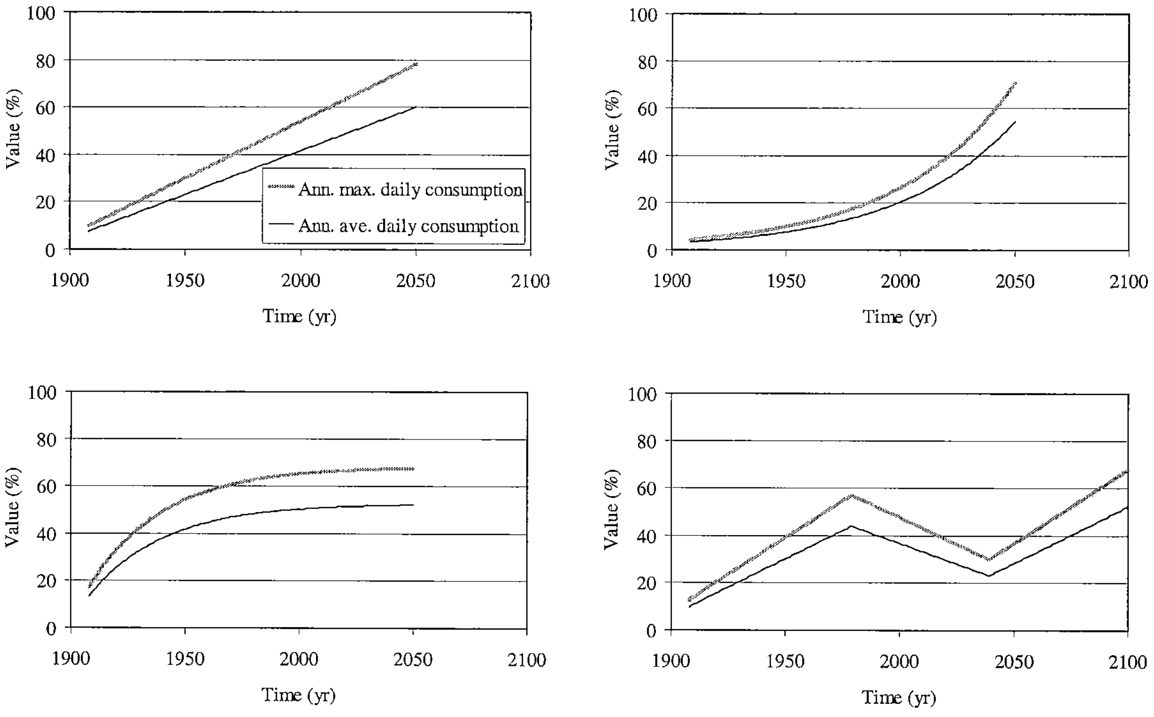

Figure 6.1: Four patterns of consumption. The vertical scale is relative, ranging from 0 to 100%.

The first pattern assumes a linear increase of consumption over time. It represents the empirical long-term consumption trend of the first half of the past century (1900 – 1970). The second and third patterns, representing an exponential increase and an asymptotic flattening of consumption respectively, in reality took place over several time periods. The rate of change is selected on the basis of empirical observations. Finally, the last pattern is characterized by two sharp bends. The first half (up to 2000) of the "sharp bend" consumption pattern mimics the past development of several cities in Switzerland. Consumption increased constantly until the seventies. After that period, industry saved water, there was a reduction of water-intensive industry, consumption per head started to drop and people moved out of the cities. A worst-case development of consumption is subsequently assumed from the point of view of the utility: demand continues to fall for a while (tempting the utility to reduce capacity), but then increases sharply again giving the utility no time to adapt to the new situation (in 2040).

6.3.2 Scenario 1: Performance of strategy A

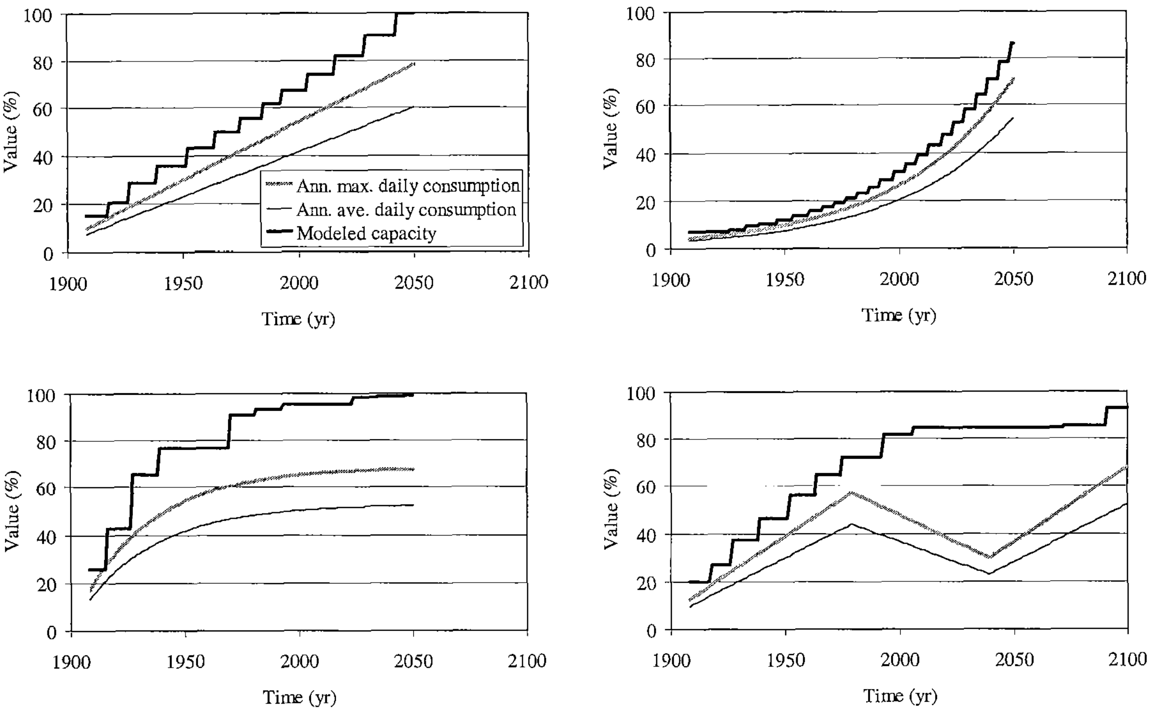

Figure 6.2: *Performance of strategy A with respect to four patterns of consumption. Although the units of the values of the vertical scale would be m^3/d, they are shown in relative terms, ranging from 0 to 100%.*

With the linear pattern of consumption, capacity increases regularly according to the capacity-building rules of the stakeholders. Small fluctuations in regularity can nevertheless be observed, resulting from rules such as the duration of the construction period or other minor effects.

The exponentially-increasing pattern of consumption results in a very frequent increase of capacity. Since the calculation of new capacity is based on extrapolating the regression of consumption data from the beginning (1908), estimations of the volume of new capacity are always too low. Hence, capacity needs to be planned frequently. So the strategy seems to be rather inefficient (and would in reality probably be changed).

The asymptotic flattening pattern results in a constant overestimation of the required capacity. Since the development of consumption flattens, the regression and extrapolation rules always predict future consumption which exceeds the real development.

The strategy performs even worse with the "sharp bend" pattern. Since the rules do not allow capacity to be reduced once it is built (due to high security requirements), the capacity reserves are very large over a period of over 70 years (2010 to 2080). This time span is longer than the expected life span of waterworks, indicating inefficient operation. Such inefficiency would be reflected in higher water tariffs and possible technical problems (e.g. non-used pumps, degraded biofilms). On the other hand, the utility is prepared if consumption were to rise again.

The performance of this strategy can now be compared with the alternative strategies B and C.

6.3.3 Scenario 2: Performance of strategy B

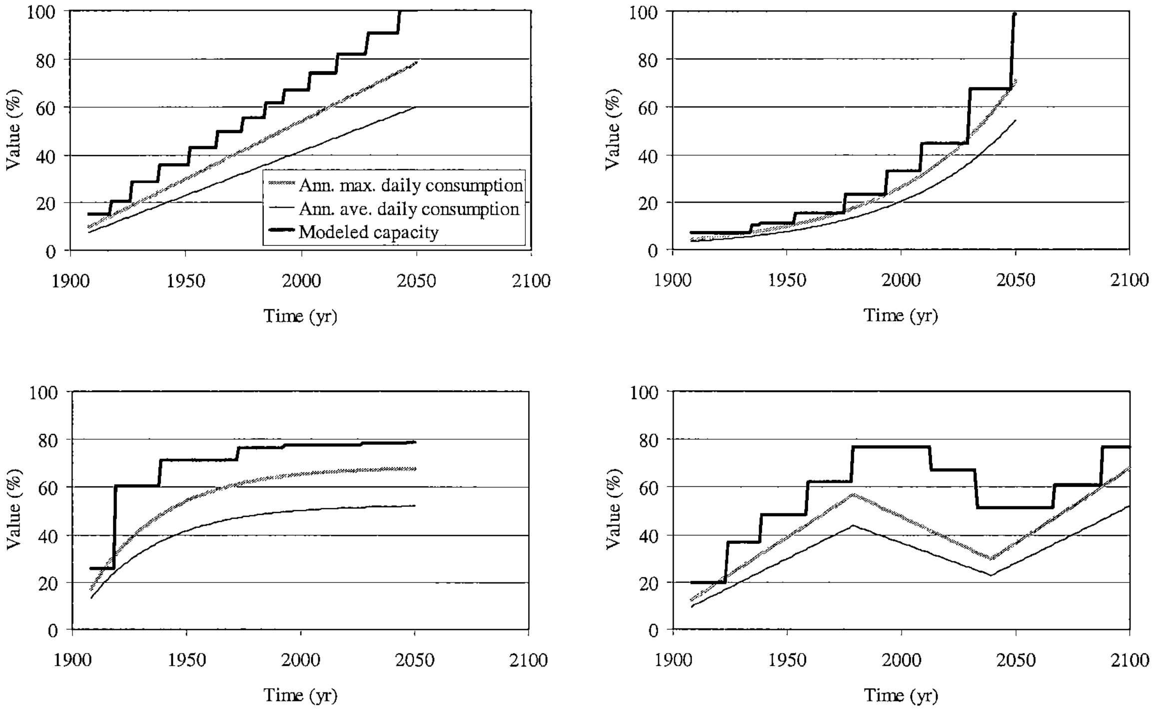

Figure 6.3: Performance of strategy B with respect to four patterns of consumption.

The linear pattern again leads to a rather regular increase of capacity similar to strategy A. The time period for the regression of past consumption data does not influence the regression result.

The pattern of an exponentially-increasing consumption leads to fewer capacity steps compared with strategy A. This is because the extrapolation of consumption (in order to determine new capacity) is based only on the regression of the data of the last 10 years. As the short-term regression can capture the exponential consumption trend better than the long-term regression of strategy A, fewer planning steps are required. Hence, strategy B can cope better with the consumption pattern, resulting in a more effective design procedure. However, the capacity reserves can then become very small or disappear altogether.

The strategy can cope well with the flattening consumption pattern. Only at the beginning of the simulation are the rules unable to allow the capacity to be adapted in time. The curve for peak consumption overlaps the capacity curve. The increase in consumption obviously outstrips the ability of the engineers to build new capacity, given the minimum reserve they want before starting a new planning phase.

The sharp-bend pattern indicates that the strategy can follow the "up and down" development of consumption. After the second increase (around the year 2060), the utility can only just supply enough water to the consumers.

Overall, it seems that this strategy can cope better with the development of consumption than strategy A. The problem remains that it can barely provide enough capacity in times of rapidly-increasing consumption (with respect to the process of planning and building new capacity).

6.3.4 Scenario 3: Performance of strategy C

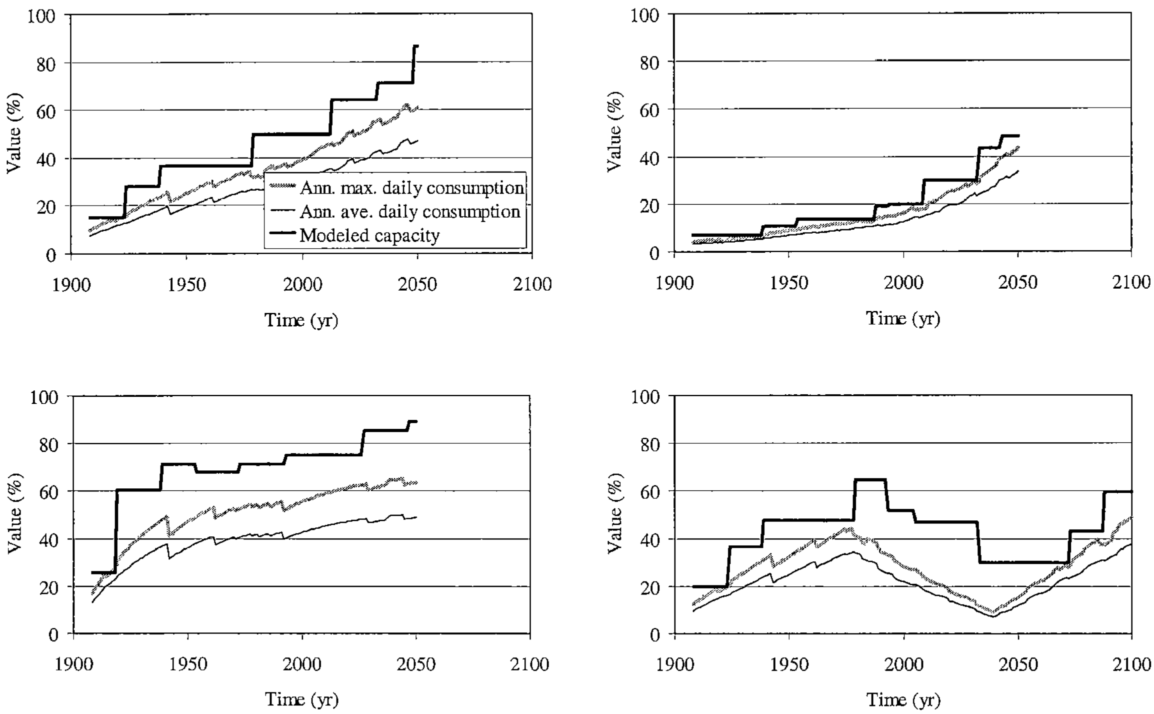

Figure 6.4: Performance of strategy C with respect to four patterns of consumption.

The third strategy influences consumers consistently (demand-side management). It is consequently assumed that consumers react to such influences. Consumers certainly react to price changes (price elasticity of -0.2) and are willing to reduce their maximum daily demand over the year(ratio to average demand by 30%) if they are influenced by the utility. Peaks are only influenced by the utility if the required capacity reserve (5%) is no longer given. The planning of new capacity is initiated at the same time.

All four diagrams show that capacity exceeds consumption at any time. If the maximum daily consumption is influenced over the year, it will decrease over time. This decrease gives the utility time to plan new capacity. When capacity is built and the capacity reserve again exceeds the required minimum, consumers are no longer influenced and peak consumption returns to its original amount (peak factor of 1.3).

The rather small price elasticity of -0.2 results in constant adaptation of the average consumption. As a result of price fluctuations (not shown), the average consumption declines when prices go up and increases when they go down. Average consumption in the sharp-bend pattern decreases to a minimum (in 2040) of 5% instead of 25% when it is not influenced. These influences add to the capacity fluctuations. Waterworks are shut down (completely or 50%) for several decades before being reopened or rebuilt. Nevertheless, capacity can be adapted in time without producing shortfalls or excessive capacity reserves.

6.3.5 Conclusions

Executing scenarios with these four patterns of consumption gives us a good understanding of how the various strategies behave in different situations.

- The "rules of the past" (strategy A) can provide sufficient capacity at any time with respect to actual consumption. Since a new planning process starts when capacity reserve is less than 20%, sufficient time is given to adapt capacity. However, this strategy cannot handle decreasing consumption trends. The supply security requirements prevent the down-sizing of existing infrastructure. This may result in inefficient operation.
- The "present strategy" (strategy B) requires less capacity reserves and the planning of new capacity is based only on the regression of recent consumption data. This strategy can cope well with fluctuating consumption patterns. However, capacity often cannot be adapted in time. Several capacity shortages occur if the increase in consumption is rapid or unexpected.
- The "present strategy including active influencing of consumers (now sensitive)" (strategy C) yields the best performance. The consistent influencing of consumers gives the utility time to plan newly-required capacity. The rules can cope with any consumption pattern if the increase in consumption is not too extreme.

It is a matter of speculation whether consumption can be influenced in the way assumed in strategy C. More research is needed to show the degree of possible influence. Indications suggest that consumers may be influenced over a couple of days (personal communication with the directors of different utilities). In certain Swiss cities, some calls to reduce water usage as a result of accidents or extreme climatic conditions led to a drop in consumption which exceeded expectations.

The scenarios with patterns give no answer as to how the strategies behave with respect to sudden consumption peaks. If peak consumption fluctuates more over the year, the above characterization of the strategies can be expected to become more pronounced. The second strategy would be even more risky. Strategy C would only cope if the influence applied to consumers were to result in a pronounced reduction of the peaks.

It seems that security of supply can be achieved in two ways. Either relatively large reserves are needed or else consumers would have to be influenced. Such demand-side management would offer a means of gaining time while adapting capacity, but would have to be communicated well to consumers (because of its possible consequences in water tariffs).

These conclusions must be validated further in the next section by applying the strategies (in retrospect) to the development of consumption in the past.

6.4 Simulations with observed consumption

The following simulations are pursued on the basis of the development of consumption observed in the past (1908 – 1996). How would capacity have developed if strategy B or C had been applied? How would capacity have developed if consumption peaks had been successfully reduced?

All subsequent scenarios are divided into four to five parts. Firstly, the *hypothesis* states what the scenario demonstrates. Secondly, specific assumptions are described (not always needed). Thirdly, in the *reasoning* part, the executed scenario is shown in a figure and discussed. Fourthly, the *reaction* of the stakeholders involved in the round table is described. And finally, *conclusions* are drawn from the scenario and the lessons learned are summarized.

6.4.1 Scenario 4: Comparison of strategies in retrospect

Hypothesis: The application of strategy B would not have provided sufficient supply security in the past. In contrast, strategy C would have been successful in the past.

Reasoning: The rules of strategy B can cope only partly with the development of consumption (Fig. 6.5, right). For comparison, the performance of strategy A (the rules of the past, Fig. 6.5, left) is shown. As already discussed above, the main problems of strategy B are the periods with rapidly-increasing consumption (around 1930) or single consumption peaks (e.g. 1976). A constant and relatively slow trend of consumption is easy to cope with even if the consumption trend is negative. This is the result of considering only the last 10 years when determining the real consumption trend.

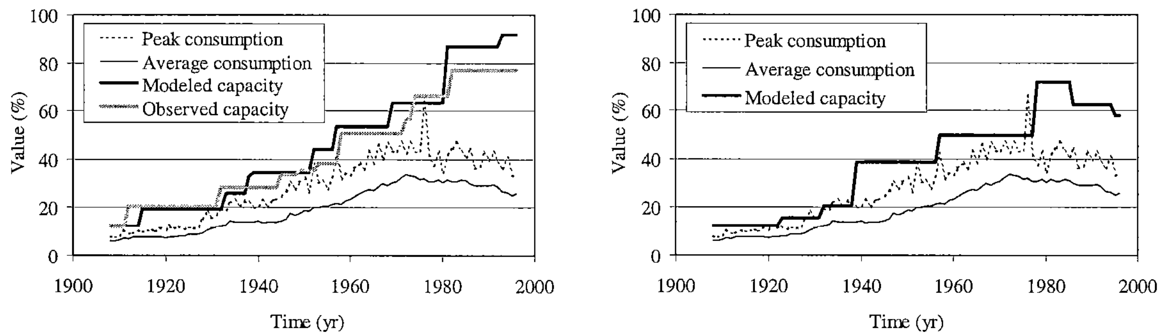

Figure 6.5: *Performance of strategies A (left) and B (right) in retrospect. See text. Although the units of the values of the vertical scale would be m^3, they are shown in relative terms, ranging from 0 to 100%.*

The capacity development due to strategy C (Fig. 6.6, left) can cope better with the consumption trend (exception: 1976, minor shortage). If capacity reserves become minimal, consumption peaks are reduced by 30% until they get smaller (in the following years) or until new capacity is built. In order to allow a good comparison with the other strategies (Fig. 6.5), average demand is assumed not to be price-elastic. It should again be emphasized that the degree of possible peak reduction is an assumption, although not an unrealistic one. More conclusive empirical evidence (of the specific utility) is needed to estimate the potential to reduce peaks more effectively.

Since significantly less capacity is built in this scenario than during the observed development (see Fig. 6.5, left), less investment is required (Fig. 6.6, right). The modeled and observed

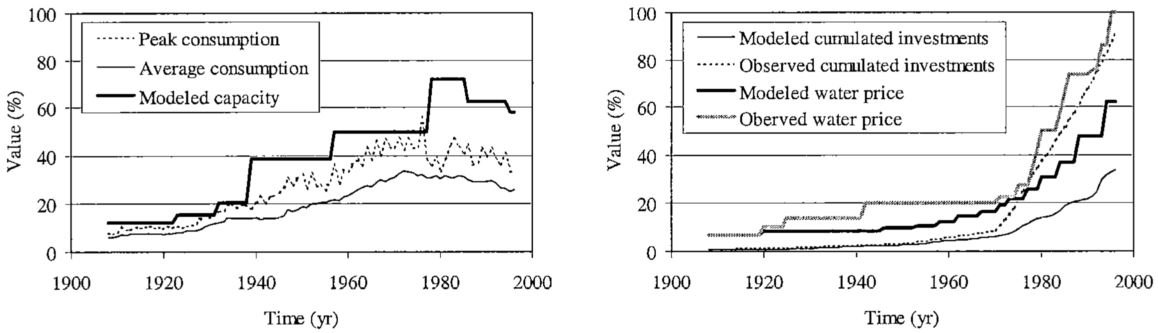

Figure 6.6: *Performance of strategy C in retrospect. Left: capacity development. Right: effects of the capacity development on gross investments and water price plus a comparison with observed values. The vertical scale is relative: all values are given in %. Investments (range: millions) and water price (range: SFr./m^3) are thus shown in the same diagram.*

cumulative gross investments differ by about 60%. This seems a lot since it is known that pipe mains account for at least 60% of overall investments. However, a first reason is the different costs for investments (lower costs per unit in strategy C). The second reason is that the main difference in capacity development occurred between 1970 and 1996. During this period, few pipes were built since the city no longer grew (only replacements were made). Investments in pipes were consequently minimal. At the same time, inflation picked up significantly during this period (see Fig. 5.3 on page 44), so that the difference in cumulative investments seems plausible.

As a result, the development of the water tariff is also affected. Figure 6.6, right, shows the modeled development of prices in comparison with the observed development. The simulated water price is lower than the observed price by about 10%. Note that the service fee is not included in the price shown.

Reaction: The reaction to these results was contradictory. On the one hand, stakeholders are not used to seeing a decrease in capacity. This image is not part of their mental furniture. They prefer to anticipate technical problems and list the reasons why a reduction suggested by the scenario may not be possible (location of waterworks, effects on network, effects of failure of waterworks etc.). The scenario is thus viewed very skeptically. On the other hand, they are relieved to see that their "present strategy" would work in times of spare capacity. Nevertheless, the question of the range of possible influence of consumers remains (peak 1976).

Conclusion: Safety margins, capacity reserves and redundancy may be reduced if consumption can be successfully influenced toward the elimination of extreme peaks. The possibility of influencing consumers so that consumption peaks are anticipated provides the needed flexibility if capacity gets short. This would be a precondition for leaner planning schemes. The ability to combine the political and socio-economic dimensions (to influence consumers and steer demand) with technical considerations (to ensure enough capacity at all times) can provide the foundation for a successful strategy.

The occurrence of consumption peaks is a critical aspect. The dominant influence of peaks will be further evaluated in the next scenario.

6.4.2 Scenario 5: Influence of peaks

Hypothesis: Single consumption peaks may influence the development of the capacity by 15%.

Reasoning: The consumption peak of 1976 is well known in water supply engineering in Switzerland. It is used as an argument for the need to have sufficient capacity reserves at all times. Accordingly, this peak provided the justification for large investments in the past 30 years. However, it did not "just happen" but was also "allowed to happen". No measures needed to be taken at the time to reduce the peak as sufficient capacity was available.

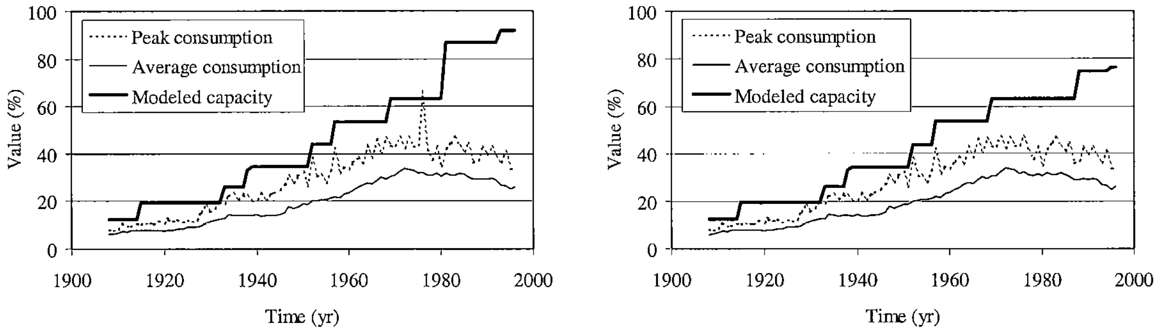

Figure 6.7: *Influence of peaks. Left: modeled capacity development influenced by peaks. Right: different capacity development if the peak of 1976 is eliminated. The vertical scale is relative (%).*

The peak (a single day in June 1976) affected the further development of capacity. The left diagram (Fig. 6.7) shows the application of strategy A in the model. Strategy A was also applied in the right diagram, but the consumption peak of 1976 was removed. The final capacity value differs when the two simulations are compared: the peak of 1976 accounts for a capacity difference of about 15%.

This effect of a single peak is plausible. If peak demand is responsible for capacity expansion, this expansion cannot be corrected again soon. Once built, existing capacity will remain until another waterworks needs to be rebuilt (e.g. due to aging).

Reaction: The stakeholders acknowledge the relevance of peaks. Although they agree that it is necessary to influence peaks at times of scarce capacity, they argue at the same time that it is a political task to "eliminate" peaks. So far, the regulations have not taken this into account.

Conclusion: Peaks are relevant, as their occurrence greatly influences the development of capacity. It is also suspected that peaks generate further peaks because the expanded capacity allows such further peaks to occur. So if lean capacity development is targeted, it is important to gain control of the peaks.

6.4.3 Conclusions

Influencing consumers and "steering demand" (demand-side management, DSM) is unavoidable given the goal of a lean but reliable supply system. Unfortunately, little experience is available regarding DSM. The experience gained by other cities cannot be transferred blindly as too many factors differ. It is thus crucial that the potential effects of influence are studied further and models of consumer behavior are developed. Such models must also be tested (validated) separately for each supply region.

6.5 Simulations of future developments

The following simulations represent future scenarios. They are performed over a time period of 104 years (1997 - 2100). One may argue that this long period does not make sense in view of the uncertainties inherent in the future. However, the goal of the simulations is to see the emergence of the infrastructure pattern. If simulations were performed over only a foreseeable period of, say, 20 years, no pattern could emerge in this short time span because the life-expectancy of the infrastructure is between 50 and 100 years.

6.5.1 Simulation assumptions

The model inputs are assumed to remain on the level of 1996 (Fig. 6.8). Annual inflation is assumed to be zero (Fig. 6.8, left) so that the price development is comparable to current price levels. The interest rate for debt, considering zero inflation, is assumed to remain at 4% (Fig. 6.8, right). The additional model inputs are also assumed to remain constant for the next 100 years of the simulation. An overview of the values of all parameters is given in the parameter list (see Appendix D).

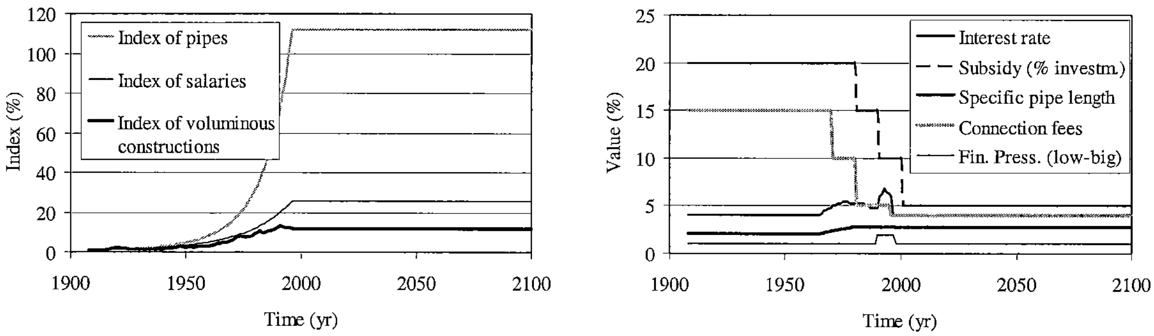

Figure 6.8: *Model inputs for simulations of the future. All values are assumed to remain at the level of 1996. The % values (vertical scale) are not relative but represent actual values (all values are % values).*

The initial values of the model variables are assumed to be at the modeled level of 1996. So the model is run with the rules of the past (strategy A) up to 1996. The results now represent the initial values for the scenarios.

6.5.2 Scenario 6a: Expected cost in the future

Hypothesis: Assuming constant consumption as well as the same rules and construction prices as in the past, water prices and debt will increase significantly in the long run.

Assumption: Constant average consumption is assumed over the next 100 years (Fig. 6.9, left). The maximum daily consumption over the year is calculated on the basis of the average daily consumption over the year by using a random factor between 1.3 and 1.7. As peaks are decisive for the development, a further artificial peak is assumed in the year 2065. It is further assumed that the construction engineer does not reduce prices as a result of zero competition (according to the rules of the past).

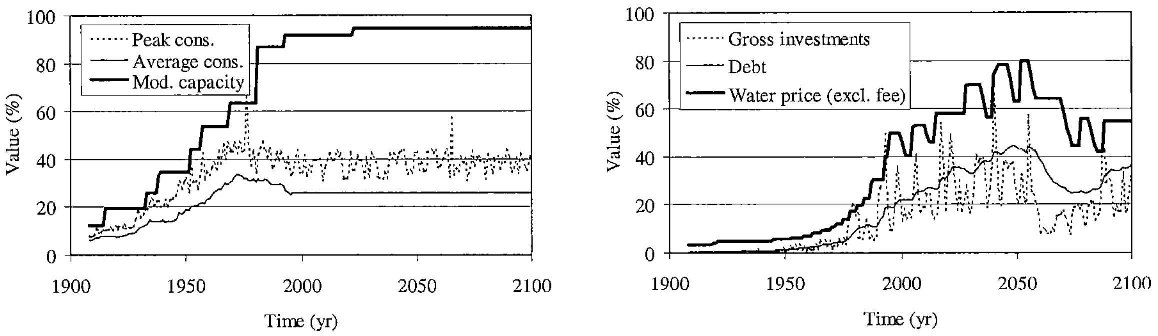

Figure 6.9: *Development of technical (left) and financial (right) variables. Constant consumption is assumed and the rules of the past are applied. Investments (range: millions), debt (range: millions) and water price (range: SFr./m^3) are shown in the same diagram.*

Reasoning: A consideration of Fig. 6.9, left, shows that capacity is slightly increased in spite of sufficient reserves (e.g. after 1995). This increase is due to waterworks reaching the end of their life span. The renovation of these waterworks means that a new planning process starts, and this produces a small increase as a result of the rules of the stakeholders involved. Toward the end of the simulation period, capacity remains constant. The planning rules do not suggest an increase and a reduction of existing capacity is not considered either.

A consideration of the right-hand figure (Fig. 6.9) shows that increasing investments must be expected up to the year 2050. These investments have their origin largely in pipes which must be replaced. In addition, the renovation of existing waterworks also requires investment. After 2050, investments decrease. Because pipes built after 1990 have an assumed life span of around 100 years, they do not need to be replaced before about 2070. However, pipes built before 1990 have a life expectancy of about 40 years (different material) and will all have to be replaced before 2050.

The varying shape of the price curve (Fig. 6.9) with its upward and downward fluctuations is a result of the strictly applied rules. If these rules were to allow for a fine-tuning of the required price, the curve would be smoother. Nevertheless, it can be seen that the price is expected to rise substantially during the next 50 years in this scenario, subsequently to drop toward the end of the simulation period.

The development of investments in the figure (right) appears to be heterogeneous, forming investment peaks and troughs. The pattern of investments would naturally be smoother in reality. A master plan of investments (required by the state) allows the utilities to flatten these annual fluctuations out.

The level of debt depends on the size of the investments. However, the slightly increasing

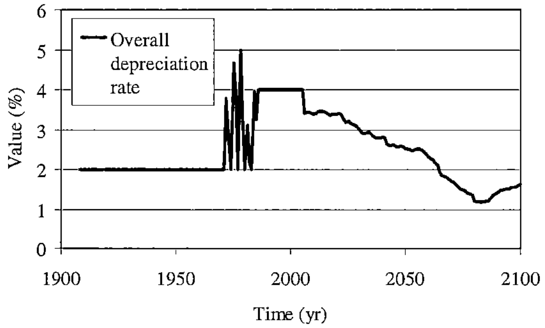

Figure 6.10: *Development of overall depreciation rate (total depreciation divided by total initial net value).*

investment trend cannot account for the dramatic increase in debt alone. Debt is further dependent on the annual depreciation. The overall average depreciation rate decreases rapidly after the year 2005 (Fig. 6.10). This trend is a result of the accounting strategy, which is expected to change in 2005. The new strategy stipulates that depreciation of a single infrastructure element will end if its book value reaches zero (annual rate 4%). Prior to this, the possible level of depreciation was further increased on other elements. This means that although a pipe element, for example, will have a book-value of zero after 25 years, its life span is about 100 years. The result is a rapid decrease in the overall depreciation rate (=total depreciation amount $\div$ total initial net value $\times$ 100) followed by an increase in debt (due to the impact of constant new investments).

Reaction: This pattern of debt surprised the stakeholders involved. Such a dramatic rise in debt level cannot be accepted by the utility. The effects of the new accounting strategy, which is expected to be put in place by the state in 2005, were not envisioned by the utility stakeholders to the extent shown in the scenario.

Another surprising factor was the drop in investments after 2050. The utility managers expect that the assumption of a 100 year life span of new pipes is too optimistic. If this life span were reduced, they would also have to be replaced after 2050 and the drop in investments would become smaller.

Conclusion: The consequences of the new accounting strategy must be further studied by the utility managers and its effect explored. Moreover, special attention must be paid to debt. This is a key variable for the utility, because once increased, it will inhibit further investments and will influence annual financial planning through large interest charges.

The next scenario is suggested by the utility managers. The development of investments and debt will be further explored by changing some of the assumptions of this scenario.

6.5.3 Scenario 6b: Strict price control

Hypothesis: A very strict control on investments together with strict competition in order to lower investment costs will result in a stable financial situation.

Assumption: Two assumptions are changed in this scenario compared with the one above. Firstly, the average life span of pipes built after 1992 was reduced from 100 to 80 years. Secondly, strong competition is assumed between engineering companies after 1996, resulting in a significant reduction of investment costs. Costs are reduced by 20% by engineering companies (based on normal costs (literature)). In addition, costs for waterworks are reduced by 30% since the type of construction has changed. Note that according to the rules of the past, costs were increased by 20% (thus yielding now a total reduction of about 50%). This assumption is realistic in view of the observed development of prices over the last 10 years. Similarly, the construction size is no longer increased by 10% as in the past in view of the need to construct more cost-effectively.

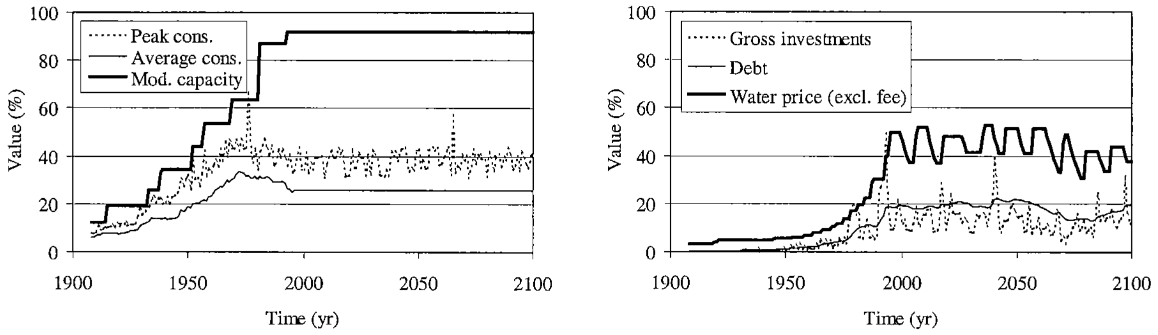

Figure 6.11: *Development of technical (left) and financial (right) variables. The utility's director and chief engineer apply the rules of the past, while the construction engineer behaves according to the present rules, so the investment costs are lower. Moreover, the expected life span of new pipes is assumed to be 80 years (instead of 100 years).*

Reasoning: The results of these changed assumptions are seen in Fig. 6.11. The left-hand figure (Fig. 6.11) differs from the corresponding figure of the above scenario (Fig. 6.9) by the absence of a slight increase in capacity in the year 2020. This is due to the changed rules of the construction engineer, who now refrains from increasing his job assignment by 10%.

The right-hand figure (Fig. 6.11) indicates that investments are considerably lower under the new circumstances. An increase in debt is thus prevented in spite of the overall depreciation rate still decreasing. As a result, the water price is also about 20% lower. Moreover, as the assumed life span of pipes built after 1992 is reduced from 100 to 80 years, the investments decrease less after the year 2050.

Reaction: This scenario provided what the stakeholders expected. The key variable of debt remains constant at the same level as today. The development of investments is now stable, which is the result targeted by the utility managers. They were relieved to observe that a constant debt development seems possible, at least with some modifications in the assumptions.

Conclusions: This is a scenario with very low investment costs. Whether these assumptions become true or not in the future is uncertain. However, a very strict cost control of investments is crucial for a financially sustainable development of the utility.

6.5.4 Scenario 7: Pipe renewal rate

Hypothesis: The renewal rate of pipe mains must be increased from current levels of 1.5 – 2% to 2.5%.

Reasoning: The budgeted annual renewal rate for pipes is currently between 1.5% and 2%. This rate is not sufficient to renew all old pipes in the future. Assuming a renewal rate of 1.5%, the fraction of expected pipe failures (pipes that exceed their life expectancy) would increase up to 20% (Fig. 6.12, left). However, if the budgeted rate of renewal were increased to 2.5%, most of the old pipes would be exchanged in time (Fig. 6.12, right). Only a few would exceed their life expectancy (around the year 2020).

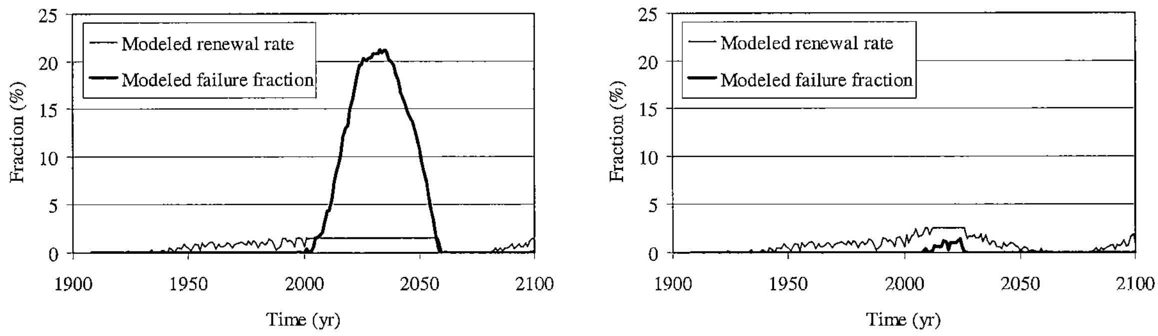

Figure 6.12: *Maximum renewal rate for pipes: 1.5% on the left, 2.5% on the right. The lower rate is insufficient to renew the pipes in time.*

Reaction: The utility managers are well aware that the importance of an adequate rate of renewing pipes in the future must not be underestimated. The scenario confirmed that the renewal strategy is a crucial factor for future developments. However, they were not specifically aware that a renewal rate of 1.5% would result in the failure of 20% of all the pipes in about 30 years (based on the model assumption related to pipes).

Conclusion: The demonstration of the effect of a minimal renewal rate (1.5%) made the utility managers additionally aware of the importance of renewing pipes. However, the renewal of pipes often depends on other pipe networks (gas, electricity, telecommunication, sewers) or on the renovation of roads. Special attention must therefore be paid to the impact of these other networks.

6.5.5 Scenario 8: Reduced life span of pipes

Hypothesis: A reduced expected life span of new pipes does not create significant problems for the utility.

Reasoning: Since the 1990s, a new type of pipe is installed when pipes are replaced. The new pipes have an expected life span of 100 years. However, no experience is available regarding the correctness of this estimation. A new type of pipe material was already used in the past (around 1960) for installing new pipes or replacing existing ones. The expected life span exceeded 80 years then too, assuming they were at least as good as the old ones. However, this prognosis was wrong, as these pipes reached the end of their life span after about 40 years (see the rule catalog in Appendix B).

For this scenario, it is assumed that the pipes built today (and in the future) have a life span of only 50 years (half the expected value). The pipes must therefore be replaced more often.

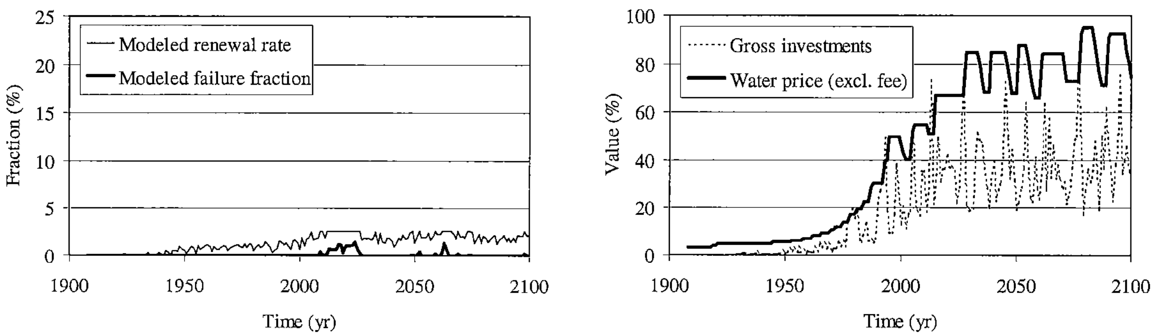

Figure 6.13: *The life expectancy of pipes built after 1992 is 50 years. The maximum renewal rate by the chief engineer is 2.5%. The level of investments is to be compared with scenario 6a (strategy A, no competition).*

Considering a life span of 50 years (adding a Gaussian distribution with a standard deviation of 10 years), the renewal rate of 2.5% is sufficient (Fig. 6.13, left). Most of the pipes can be replaced in time when they reach the end of their expected life span. After the year 2050, investments and water prices remain high (Fig. 6.13, right). As a result, pipe replacements would not cease after 2050 (see Scenario 6a) but continue due to the shorter life span. In addition, the level of investment and water prices after 2050 is about 20% higher than that in scenario 6a.

Reaction: This scenario did not produce any specific reaction from the stakeholders involved. The unexpectedly short life span affects the development of investments and water prices, but is not a surprise. Furthermore, this is not considered to be a likely scenario by the stakeholders.

Conclusion: The results showed that the utility would not face any additional problems. Although both the level of investment and the water price would be higher, they would be fully justified. The increase in water price would then be continuous. This is seen as being less problematic than rapid changes.

6.5.6 Scenario 9a: Reducing capacity reserves

Hypothesis: A reduction of capacity reserves in combination with the introduction of demand-side measures does not diminish supply security even with a worst-case consumption development.

Reasoning: A sharply bent future consumption trend is an important scenario from the perspective of the utility. This is actually a worst-case scenario, as the change in trend is hard to foresee and planning may consequently not capture this situation. It cannot avoid being wrong at the time of the change. This is often the reason why utilities fail to reduce existing capacity reserves. So the question is whether a capacity reduction can be accepted in spite of the danger of trend changes.

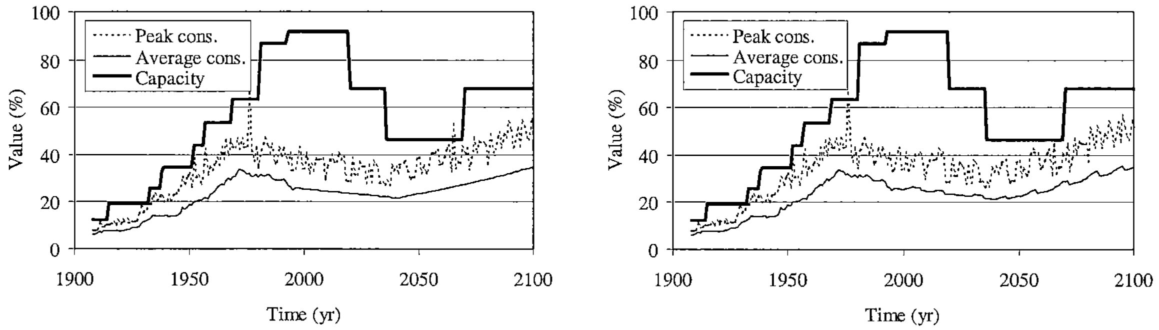

Figure 6.14: *Trend up to 2040: -0.2%/yr for population, -0.2%/yr for per capita consumption. Trend after 2040: 0.4%/yr for population, 0.4%/yr for per capita consumption. Left: No price elasticity or peak reduction. Right: price elasticity of -0.2, 30% peak reduction.*

The change in consumption trend is assumed to occur in the year 2040 (Fig. 6.14). The sharp bend is deliberately chosen at that time, since capacity is reduced just before this (worst case). In addition, an extreme peak is assumed at 2065, adding to the worst-case assumptions.

The "present rules" of the utility's chief engineer and director as well as the construction engineer are applied (Strategy B, Fig. 6.14, left, after 1997). Capacity is subsequently reduced due to the large reserves available up to the year 2040. However, this strategy fails to adjust capacity in time (peak at 2065). The planning procedure for new capacity starts at about 2062, but capacity is not built before 2066 due to the time lag of construction.

The performance of strategy C is shown on the right (Fig. 6.14). A consistent influencing of consumers is assumed, resulting in their visible price and peak sensitivity. As a result, the peak value at 2065 can be successfully influenced and reduced by 30%. Because consumers can be influenced over short periods (a couple of years), more time is available for adapting capacity.

Reaction: The utility managers acknowledge the need to reduce existing capacity if the decreasing consumption trend continues. However, one of their concerns is the effect of a reduction on the pipe network. The distribution of large and small pipe diameters may become a problem (hydraulics). Such effects are not modeled. Moreover, this simulated reduction is viewed skeptically. It is doubted whether price effects will justify the risk of minimal capacity reserves.

Conclusion: The scenario shows that it is possible to reduce capacity without losing security of supply. However, many details must still be examined in order to explore the idea of reducing reserves and aiming to create a much leaner infrastructure.

6.5.7 Scenario 9b: Effects on water tariff

Hypothesis: Reducing capacity will affect water tariffs by 10%.

Assumption: Figure 6.15 depicts the development of investments, debt and water price. The sharp-bend development of consumption is assumed as above. For the left-hand figure, the rules of the past are applied by the utility's chief engineer and director (capacity remains at high level). In contrast, the construction engineer is assumed to apply the present rules, so that prices are reduced (comparable to scenario 6b. Not exactly the same as life span of pipe mains is different). Strategy C (present rules and sensitive consumers) is applied for the right-hand figure after 1996.

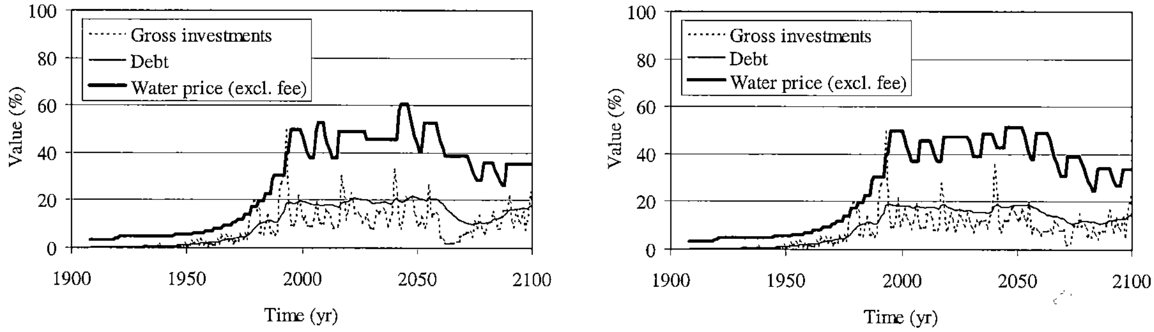

Figure 6.15: *Financial effects of strategy A and strategy C. Trend up to 2040: -0.2%/yr for population, -0.2%/yr for per-capita consumption. Trend after 2040: 0.4%/yr for population, 0.4%/yr for per-capita consumption. Right: price elasticity of -0.2, 30% peak reduction. All values are depicted on a relative scale (%). Investments and debt are based on a scale of millions, water price on a scale of SFr./m^3*

Reasoning: The difference in the financial variables is minimal and is in the region of 10% for the water tariff. The influence of reduced capacity is limited because the reduction in capacity also incurs costs (e.g. adaptation of the piping system). Moreover, many pipes must be replaced over the same time period, representing the major part of investment costs.

Reaction: The minor effect of a capacity reduction was expected by the stakeholders. The range of price difference did not surprise them.

Conclusion: A reduction of capacity reserves has minor effects on the water tariff. Although this effect should not be neglected, it must also be communicated to possible political stakeholders that the price does not depend predominantly on capacity. An additionally reducing effect on price however (10%?) can be expected in the long run by the possibility to design pipe mains smaller.

Note that shut-down costs were assumed to be as high as renovation costs (shut-down only if load = 50%; costs = 0.5 (load) × 0.5 (shut-down or renovation) × function of total capacity).

6.5.8 Scenario 9c: Sensitivity to assumptions

Hypothesis: Minor changes in the assumptions of the scenario may result in an altered pattern of capacity development.

Assumption: Three minor changes are made for this scenario compared to scenario 9a: First, the population trend from 1997 to 2040 is only -0.1% per year instead of -0.2% as in the two scenario above (9a). Second, the per capita consumption trend is reduced to -0.1%. And third, a price elasticity of -0.4 is assumed (Fig. 6.16, right), instead of -0.2 as in the scenario above (9a).

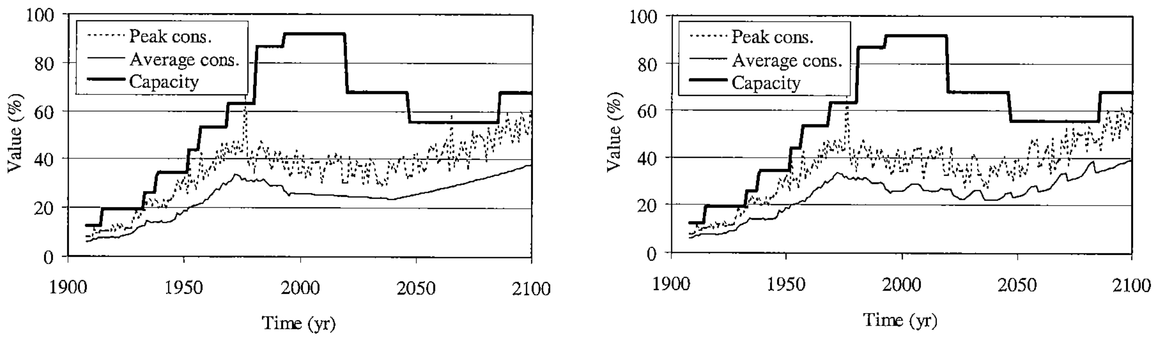

Figure 6.16: *Trend up to 2040: -0.1%/yr for population, -0.1%/yr for per capita consumption. Trend after 2040: 0.4%/yr for population, 0.4%/yr for per capita consumption. Right: price elasticity of -0.4, 30% peak reduction. All values are depicted on a relative scale (%).*

Reasoning: The development of capacity is now different. When comparing the figures with the ones of scenario 9a, one can recognize the different development of capacity. These differences are obviously due to the thee changed assumptions. But although the changes were minor, the development is quite different. Especially the amount of capacity reduction (around the year 2030) changes.

Reaction: This scenario was not shown to the stakeholders (created after the last meeting).

Conclusion: Because the simulations react sensitively to minor changes in the assumptions, the model cannot yet be used as a predictive tool with respect to details. It can, however, demonstrate and visualize the effects of such changes in assumptions and give a good insight into the system dynamics. The patterns of development remain the same.

6.5.9 Conclusions

When applying the model, the observer must not focus on the details of the variables developed, as minor changes in assumptions change these details. The main focus must be on the general pattern which emerges. The important point is the resulting trend in the development of the variables, and these trends are - on the basis of the scenarios performed so far – robust. However, since the simulation spans a time period of nearly 200 years, many uncertainties and restricted predictive powers of the model must be accepted. A next step could be to go further into analyzing major sensitivities and their consequences for the planning process.

The presentation of most of these scenarios to the stakeholders involved is a crucial step in the modeling procedure. The stakeholders confirmed that the discussion of the scenarios was interesting. Their intuition of future risks for the water utility was partially confirmed. In addition, their awareness of new risks was sharpened.

A further discussion of the scenario simulations is given in the next chapter in section 7.3.

Chapter 7

Discussion

The advantages and limitations of the methodology (chapter 4), the development and validation of the model (chapter 5) and the scenario simulations (chapter 6) are discussed. The discussion is structured by stating a hypothesis and then reasoning its content. A main strength of this methodology is to structure the procedure and visualize the influence of stakeholder behavior (rules). Although the model and the scenario simulations are the visible results of this process, the process itself is the most important part. Following this discussion, the importance of incentives is emphasized and measures are proposed of complying with the findings in the previous sections. These findings highlight a new risk of excessive security of supply and the potential benefits of demand-side management. Finally, the research tasks initially formulated in chapter 1 are critically reviewed.

7.1 Methodology

The methodology has so far been applied in one case study. The experience gained there is both satisfying and promising, but it is too early to make a conclusive judgment about the usefulness of the methodology. Nevertheless, some major aspects which characterize this approach are highlighted.

The main **findings** are:

- *The combined use of diverse tools is the only way of creating an effective discussion platform for stakeholder behavior.*

  The methodology consists of two parts which are connected but are totally different by nature: the first (rule catalog) is a tool taken from the social sciences which is connected to the second tool (a computer model) predominantly familiar to technical scientists. Neither the rule catalog nor the model alone would be sufficient to achieve the project goals. Neither surveys and interviews nor interesting diagrams and dynamic screens alone would convince stakeholders of the relevance of focusing on their behavior. In addition, the rule-finding process is motivated by the subsequent building of a model, and this model is in turn based on rules which were evaluated by the stakeholders themselves. The participatory process combines the two parts and provides the basis for gathering the required information. Furthermore, this process prevents misinterpretations of the model outputs.

- *An "engineering approach" can successfully provide the foundation for fruitful discussions and capture the essence of the interactions.*

No matter what type of methodology is used, it is hardly possible to identify the complete set of rules which govern the interactions between the stakeholders involved. In fact, the rules showing the stakeholder interactions will always be incomplete, abstract, generalizing and rigid. Hundreds of rules, grouped together and mutually dependent, would be needed to fully comply with the complexity of today's decisions. In addition, the rules in reality are also evolving.

The current methodology follows a path which resembles a typical engineering education. Many different aspects of various professional disciplines are covered, not in full detail but to a degree allowing the problems to be solved. Correspondingly, stakeholders are represented in a "simple" manner. Thus they neither possess a changing mental representation of the world nor is their behavior adaptable (the model agents cannot deviate (learn) from their annual rules). However, the methodology has succeeded in merging the various fields, but is not optimized in detail in any particular field. Professionals from the fields of sociology, artificial intelligence, information science, psychology, economics and water-supply engineering respectively may be able to develop the methodology further in their specific domains and thus enhance its value. Nevertheless, the methodology successfully provides a framework for coping with complexity and addressing behavior.

Despite the many ways available of improving the methodology, Conte et al. (1998) ask the following question: "How should one combine a more sophisticated agent model with the simulation of qualitatively and quantitatively significant social phenomena?". This involves a trade-off: models are either small and contain complex agents acting in abstract terms, or else agents are simple but act in systems of large dimensions involving empirical data. The present methodology features the latter approach.

- *The methodology can structure the discussions of stakeholder behavior and the future development of the utility.*

  The absence of a common structured basis generally constitutes a major problem when discussing the tasks, interactions or interests of stakeholders. Stakeholders often have strong feelings or opinions with respect to behavior: "stories" are often told on the basis of many years of professional experience, especially regarding the interests of other stakeholders. However, it is difficult to channel and use this information. Alternatively, the present methodology offers a simple approach to discussing "facts" in a clear and structured way. The arguments are broken down into assumptions, claims or evidence in the rule catalog. These rules then become interlinked and are visualized in the model output (diagrams).

  Stakeholders have their own – often diverging – intuitions about the future trend of development of the utility, but such intuitions are hard to communicate via well-founded arguments. By executing "what-if" scenarios, this intuition can be compared with the model output. With their aid, one's own expectations can be described clearly or at least in a better way.

- *It is beneficial to the overall process if the stakeholders understand the mechanics of the model.*

  Building a rule-based model bears some similarity to the concept of fuzzy logic (Zadeh, 1965). In particular, mathematical equations from the model are represented by easy-to-understand sentences (rules) which make more sense to those not involved in model-building on a daily basis. Stakeholders can therefore better understand the functioning of the model. In addition, the model and its documentation is created by the stakeholders themselves. This helps them to understand the model output rather than simply marveling at a "magic" model.

In spite of these positive aspects of the methodology presented here, some problems remain which it cannot address to a full extent. The main **limitation** are:

- *Special attention must be given to any distortion of the information received. The current methodology complies with this problem in part.*

  A major problem is to ensure that the stakeholders give accurate information about their behavior. Several possible ways of distortion have to be taken into account. A first danger is that the information received may be distorted as a result of misunderstood questions or unclear answers. This danger is unavoidable when working with the interrogative research methods used in sociology. A second danger is the constant concern of stakeholders not to "lose face". Answers may be slightly elaborated in view of the need for prestige (Bortz and Döring, 1995). How can stakeholders actually admit that some of their behavior may be somehow self-centered? As with all human beings, it is not easy to actually admit a touch of egocentric behavior. The current methodology cannot solve this problem, although a first step is made to take it into account: past rules are separated from present ones. This distinction allows stakeholders to dissociate themselves from past strategies (applied either by their predecessors or by themselves) and thus partly ensures that these past strategies are less distorted.

- *The main driving forces (interest, best practice, organizational structure etc.) are expected to stabilize the patterns of behavior if the boundary conditions do not change.*

  The dynamic ways in which interactions and institutions may change add to the difficulty of the task of revealing them. So if boundary conditions change, existing behavioral patterns will also change. The goal must therefore be not only to establish a firm view of existing patterns but also to understand how and when they change. The methodology described does not address this situation explicitly. During the validation phase (1908 – 1996), it is assumed that the main pattern of rules does not change since the boundary conditions (e.g. the consumption trend up to the 1980s) remain unchanged. This means that the rules evaluated in conjunction with the stakeholders are also applicable to a time period when the interviewed stakeholders were not yet part of the system (e.g. 1908). This assumption could be further analyzed.

7.2 Model development and validation

On the basis of present experience, the main **findings** are:

- *The agent-based model structure is well suited for this type of research questions.*

  Not a great deal of experience is yet available with agent-based models, especially those relating to entire water supply systems and involving empirical data. The advantages of agent-based models compared to traditional equation-based ones for cases like the present have been discussed in chapter 3 or e.g. in Van Dyke Parunak et al. (1998) or Gilbert and Troitzsch (1999). Some main advantages are that agent-based models are easier to construct, support direct experimentation more effectively ("what-if" scenarios with stakeholders), can be validated at individual level and are easier to translate back into practice.

- *Structural similarity between modeled and observed data is achieved in spite of the many simplifying assumptions.*

Many assumptions must be made in the model to simplify the overwhelming variations found in reality. For example, subsidy rates vary according to the type of infrastructure to be subsidized. Such variations allow developments to be directed in specific ways. In the model, however, subsidy rates are the same for all types of infrastructure. Although such a leveling of variations is necessary, it does not significantly affect the quality of the model. Although the development of modeled and observed variables is not comparable in all details, the general trends of both curves match. The patterns of variables which emerge are robust (according to the sensitivity analysis). This structural agreement must already be considered a good result in view of the limited stage of understanding of stakeholder behavior and interactions (Hornberger and Spear, 1981). Of course, the existing model could be improved through further discussions with the stakeholders, and more rules could be added which incorporate an even greater amount of detail. However, it must be clear that it is impossible to aim for a perfect model calibration. All the degrees of freedom available to the stakeholders cannot be included.

- *In order to act as a basis for discussions, a model must be comprehensive and include both technical and economic aspects.*

  Both technical and financial aspects and their interactions are modeled. They influence each other, limit each other and are dependent on each other. This comprehensiveness is crucial when discussing the model with stakeholders. A model containing only technical but no financial parameters would not be taken seriously. Half of reality would be missing. Furthermore, as a result of this comprehensiveness, the model can provide a basis for discussions about the exchange of technical information to people dealing with finances and vice versa, thus supporting the exchange of technical and financial viewpoints.

The model was developed on the basis of many assumptions which lead to restrictions in its applicability. The main **limitations** are:

- *It must be assumed that the model still contains programming errors.*

  All programmers would probably agree on the fact that almost every program contains errors (bugs). So the possibility of such errors cannot be excluded from the present model either, and its outputs may be misleading. Moreover, the rules may be translated badly into computer code. However, this concern is muted because the results are discussed with the domain experts and compared with their intuition. Drastic programming errors may be detected in this way. In any case, this concern should not lead to non-acceptance of the model. After all, it is not merely the final model but in particular the process of model building which constitutes the important step to gain understanding.

- *Further model validation with data from a second utility would enhance confidence in the model.*

  A problem of the current model is that validation is not fully independent: the model builder (knowledge engineer) sees how the model behaves but he is also part of the participatory process. If a rule is missing, the knowledge engineer can propose a new rule and calibrate it with the observed data. Although this new rule has to be discussed with the stakeholders, they can acknowledge its correctness quite quickly. It is quite easy to say "yes". Further validation would thus be desirable. The existing model could be applied to the utility of another city. This second utility should be similar to the first one in terms of its organizational structure (e.g. its degree of independence from the city authorities), types of resources (lake water, ground water, spring water), density of population and size of the city etc. A further requirement is the availability of data which reaches back far enough to allow the development over time to be examined. Such further validation with a second utility has not been pursued due to the limited time constraints of this project. However, it is assumed that most of the rules are generic (since they are kept simple and straightforward). It should also be possible to model other utilities if the boundary conditions are similar.

- *The uniqueness of the rules has not yet been confirmed.*

  Although the replication of the observed data is surprising, the evaluated set of rules and parameters may not be the only one which can achieve these results. There may be other combinations of rules which could produce the same goodness of fit. This does not mean that the existing rules are wrong, but it cannot be excluded that other rules also produce results of the same quality. A further thorough sensitivity analysis would enhance confidence in the uniqueness of the rules.

7.3 Scenario simulations

The scenarios sharpen the awareness of the stakeholders with respect to possible future developments. Many results may be expected by some stakeholders but not by others. The model and simulations therefore provide the means to communicate what may happen in the future on a firm basis.

The three main **findings** are:

- *A main benefit of the model is its potential to be used as an idea generator.*

  Given the uncertainty and the various restrictions of the methodology in general and the evaluated rules specifically, the model cannot be used without further ado for predicting future states of the utility. Although the model can simulate the future development of the variables, the results have to be reviewed carefully and skeptically. It should be viewed as a basis for discussion, as an idea generator producing data (scenarios) and as an instrument to be added to the personal experience of each water expert.

- *A new risk of excessive supply security must be balanced with the traditional risk of insufficient supply security.*

  The scenarios showed that considerable capacity reserves develop when the past rules are applied. These reserves are built in order to provide sufficient supply security. However, they may also generate new risks. On the one hand, utilities are currently under pressure by the public to prove their efficient operation (see chapter 2). If this is not possible, the utility is exposed to interest groups which may interfere at political level: public votes are requested, necessary price adjustments are turned down, the reputation of the utility is questioned, privatization is demanded etc. On the other hand, large capacity reserves may bring technical problems. Possible consequences are stagnant water with loss of quality, damage to pumps because they are never in operation and filters losing their biofilm.

  The past concept of increasing the security of supply by means of large redundant infrastructures can be opposed today by the equally important goal of political freedom of action and the need to work efficiently to full capacity. The traditional concept of high supply security must be adjusted to the circumstances and a search must be made for other ways of achieving a reliable water supply system. The traditional concept and rules need to be carefully but skeptically rethought in the light of these new developments.

- *The introduction of demand-side management (DSM) is a promising step for creating mutual benefits for both utility and consumers.*

  Uncertainties in the development of consumption can be covered with the aid of large infrastructures but also with demand-side management. DSM emphasizes demand management and conservation as potential alternatives to increasingly expensive new capacity[1]. Such a strategy was applied in the scenario simulations (strategy C, chapter 6). The implication is that reductions in demand can have a significant positive impact on long-term benefits. In the near-term, however, because capital expenditures largely represent fixed costs, reduction in demand could lead to revenue losses. The magnitude of this shortfall will depend on the demand-dependent elements of the rate structure.

  Normally, water demand management is applied as an option to *reduce* demand with respect to the available capacity (saving water). However, it can also be applied to *balance* demand (no peaks) and therefore to reduce the uncertainty of the further planning process. Consumers can be influenced over short periods (a few days, by the media, political appeals etc.) to reduce peak consumption (as in strategy C). In addition, the installation of water-saving sanitary technology, such as water-saving shower heads or toilets, would also lead to smaller peaks but simultaneously affects average consumption. Two benefits result: the first is that as potential extreme peaks are influenced, they are no longer supposed to occur. Capacity reserves designed to capture extreme peaks are no longer needed. The second benefit is that the range of uncertainty of how future average demand will develop (upper end by an assumed increasing trend, lower end by an assumed decreasing trend) will be narrower. If the technical potential to save water (by water-saving shower heads, for instance) is used up, then water-wasting habits have less effect. The upper range of possible development will be lower, the lower range will stay the same. The total range of possible development in consumption is smaller. Extensive reserves designed to cope with the large uncertain range will no longer be necessary. The downside is that the price of water will increase in the short-term due to lower consumption as the fixed costs of the utility remain the same. However, the total annual costs for consumers will not rise. Public acceptance toward the utility may improve, since inefficient-looking reserve capacities will be smaller. However, it must be clear that a potential reduction of capacity reserves will not lead to dramatic price reductions (approximately 10-20%). Moreover, the public has to be aware that this rather small reduction in tariffs is compensated by the fact that consumption may be influenced over a period of a few days (the freedom to use as much water as desired may be limited within a couple of years until new capacity is built if really needed).

  From the viewpoint of the utility, the main arguments for considering DSM are neither to save water nor to reduce the water price. The main argument would be to enhance flexibility. A balance has to be found between operational flexibility (which alone would require larger infrastructure), strategic flexibility, efficient use of the infrastructure, low costs and public acceptance. It is also important to find ways of switching the existing underlying concept of constant economic growth to concepts featuring the long-term preservation of the infrastructure and public acceptance.

Two main **limitations** must be noted:

[1]DSM has its roots in energy planning, but has also become more popular in water engineering (Baumann et al., 1997). DSM is also known under more general terms such as Integrated Resource Planning (IRP) (Beecher, 1995) and Least Cost Planning (LCP). The goal of LCP is to minimize the cost to society of meeting the demand for utility services (Berry, 1992). Demand-side management (IRP, LCP) is often used by the electricity utilities, especially in the USA. In Switzerland, however, the concept is rarely applied or not even known.

- *The scenario simulations of the future could be improved by calibrating the initial conditions.*

  The initial values for the scenarios of the future (in 1997) are taken as the modeled ones according to the rules of the past (modeled from 1908 up to 1996). Therefore, the scenarios start with initial values which are not the same as the observed ones. For example, the modeled age distribution of pipe mains differs from the distribution observed in 1996 (see chapter 5). So the scenario simulations do not start with a calibrated set of variables. These deviations enhance the uncertainty of the scenarios.

- *Some rules needed for the scenarios are hypothetical.*

  The various rules of the model are validated from 1908 up to 1996. For the scenario simulations (1997 – 2100), more rules are incorporated in the model and these are vaguely validated by only partly discussing the rules with stakeholders (and not by comparing them with the observed data). Hence, the scenarios do not have the same quality of validation as the model rules up to 1996. An example is the set of rules designed to downsize waterworks. In spite of the fact that these rules are based on engineering knowledge and thinking, they have never been put into action so far and so are hypothetical. A second example is the set of consumer rules which make demand price-elastic.

The rules of behavior constitute the principal components of the model. These rules were developed in the past according to the tasks assigned to the stakeholders, but also according to their interests and the incentives given by their environment (market, regulations, expectations, culture etc.). Within the framework of the incentives, the interests direct the way in which the tasks are solved. If a different behavior is targeted, the incentives must also change. The role of incentives must therefore be further discussed.

7.4 Web of incentives

The interests of the stakeholders are the principal driving forces which guide this development. They can be directed toward the public interest, but also toward private benefits. Any discussion about the presence and effects of *private* and ulterior motives of the stakeholders in particular is taboo in the water-engineering community. And yet they influence the overall behavior, although not exclusively. Examples are ways of maximizing profit (and thus building larger infrastructure than needed) or enhancing reputation (and thus building their own infrastructure instead of sharing it with neighboring utilities). Together with the need for sufficient supply security or the need to minimize the risk of system failure, such ulterior motives may also be responsible for building an infrastructure-focused supply system: large capacity reserves, inefficiently used pipe mains (due to extreme variations in demand), acceptance of high water consumption etc. These motives are not negative at all. The possibility to optimize and fulfill ones interests is a crucial driving force for development. The main problem is that these private interests are not apparent to an outside observer, that they are hidden and thus not debatable. An analogy can be drawn to an iceberg (Fig. 7.1): Only 10% of the total volume of ice shows above the surface of the water. The main and most important parts are below the surface and are thus invisible to an observer.

When the rules of behavior were applied in the past, a win-win situation resulted for all relevant stakeholders. Both private and public interests were satisfied at the same time so that a reliable supply system developed.

However, new influences and demands on the water supply system challenge the future path of development (e.g. aging of pipe mains, declining consumption trend, increased demand for financial effectiveness etc.). Existing incentives may lead to a questionable development of the

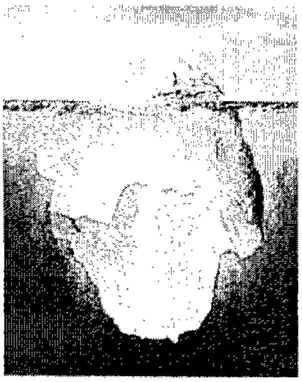

Figure 7.1: *Only the tip of an iceberg is visible from above the water surface. The crucial and supporting parts are below the surface and invisible to an observer (source: Credit Suisse, Orientierung 108).*

system from the viewpoint of least cost and overall benefits to society. An example: the large subsidies paid by the state in the past (e.g. as happened in the late 1980s) tempted planners, engineers and politicians to build more and on a larger scale than necessary. It made sense to utilize the subsidies before the state reduced or even stopped them (e.g. beginning of the 1990s). Infrastructure was sometimes built as fast as possible without detailed investigation regarding its need. Hence, the development was directed by financial incentives from the state rather than by detailed technical or system-related considerations and needs.

If the design and supply concepts are to be adapted to the new situation (e.g. declining demand, financial focus, political skepticism, renewing existing infrastructure), then the web of incentives must also be changed. Incentives should be increasingly directed toward the *services* to be provided rather than toward the flow of water to be maximized. This is not yet the case.

An example of an existing problematic incentive is that it does not pay for engineers to invest their time in optimizing rather than enlarging existing or new infrastructure. It does not pay to take the risk and compensate size by optimizing operations. Ultimately, engineers would earn less, run a greater risk of liability and may lose their reputation if something goes wrong.

Incentives are seen extremely important and guides the development. This topic is a prime area for further exploration.

7.5 Proposed measures

The external economic and political circumstances mentioned above urge and force utilities to adapt their priorities from technical security toward overall cost-effectiveness. This thesis cannot conclusively suggest the ultimate way of adapting incentives, strategies and rules for designing and operating water supply systems in the face of an uncertain future. Whether and how to apply an anticipative strategy such as demand-side management is not yet obvious to Swiss utilities. On the one hand, the application of DSM appears promising and may bring considerable benefits over the long term. On the other hand, the water price is not supposed to rise in response to political expectations over the short term. This can only be achieved by trying to keep the utilized water volumes high (average consumption is already decreasing). A way out of this dilemma would be to influence only the extreme peaks. These are the cause of the utility's long-term problems but rarely have any influence on overall consumption. However, since consumers are then also more aware of their water use, the related costs and the cost-saving potential in general, average consumption may also decrease to a certain degree.

The following measures are proposed as a first step to transform and redirect existing strategies. Emphasis is placed on three main aspects:

City-wide experiments with DSM. The potential of steering consumer demand and anticipating their behavior must be further explored. To do so requires studies to be performed which lead to models of consumer behavior. The results of these studies must be specifically tested with city-wide experiments. People in different cities may react differently, depending on their culture, traditions or the price structure. Therefore, experimental results cannot merely be taken from the literature and transformed blindly for application to the consumers of the utility in question.

A further crucial point is to perform such studies before it is "too late". A knowledge of consumer behavior and experience relating to the possibility of reducing peak consumption must be gained before a dramatic consumption peak occurs. Also, the public needs time to understand the benefits and drawbacks of such a concept.

Obtain political approval. The goal of avoiding consumption peaks should be targeted as an overall strategy. Since DSM is primarily a political decision, the characteristics of such a strategy should be made clear to the political decision-makers. This includes a demonstration of the risks of excessive supply security. Political approval should be obtained for switching the existing concept of supplying as much water as needed to a concept including DSM and a leveling of consumption.

Change incentives. Incentives should be changed so that it makes more sense for engineers to optimize concepts and current infrastructure as opposed to building new infrastructure. Thus, for example, incentives for building new infrastructure must be replaced by incentives to study consumer behavior. The reduction of uncertainties should be achieved by optimizing the overall system.

Similarly, the incentives given to consumers should be changed. Currently, the price per m^3 of water is the main measure affecting consumers of water services. If consumers save water, the price will rise due to the fixed costs. To pay a higher price as a "thank you" for saving water would irritate consumers. Therefore, the focus should be placed on the total annual cost of water services. If consumers save water and the water price rises, the annual costs would still stay the same. This does not mean that water metering should be stopped and billing based on consumption should be switched to fixed-price annual billing. The concept of the annual cost of water services is a didactic tool and must be communicated to consumers in that sense.

In conclusion, the general recommendation is to begin shifting the direction of strategies. There is still a long way to go and many details remain unclear. Regulations need to be changed, political discussions initiated, consumer behavior studied, the concept of DSM refined etc. Such a shift cannot be forced, but must be addressed pragmatically.

The following suggestions must be viewed simply as ideas. They are not discussed thoroughly in this dissertation, but are intended as hints which are submitted for consideration.

- *Expand range of products.* Utilities may consider broadening their range of products. Why only sell water? Why not sell (or promote) sanitary technology as well? Such an expansion of the products sold would mean selling water *services* instead of only selling *water*. The utility could conclude contracts with sanitary companies and could actively promote the installation of better household technology (subsidizing technical demand-side measures). In turn, the utility would profit from the revenues of the company. As a result, water consumption would be lower, leading to the long-term benefits discussed above (chapter 7.3).

- *Create research forums.* This type of research is new. It is hoped that this project serves as a good example to demonstrate the relevance of the topic and the potential to create new knowledge. The establishment of a Swiss working group would further promote or question this kind of research as well as the distribution of the knowledge which it yields. Representatives from the academic world, industry, public/private utilities and politics should gather to further discuss and develop the potential benefits of introducing new supply concepts.

- *Adapt education.* On a more academic level, training for the engineering profession needs to integrate a deeper knowledge base of the economic and social sciences. Today's problems of urban water management cannot be judged and discussed within the framework of engineering disciplines alone. Rather simple cost calculations of alternative solutions to an engineering problem are no longer sufficient. The problems of capital costs, long-term debt, lock-in effects, stakeholder behavior, incentives, loss of flexibility etc. must be further integrated into the thinking and thus also the education of the engineers.

7.6 Reviewing research tasks

Eight research tasks were formulated at the beginning of this project. All of them relate to the socio-economic or socio-technical environment of water supply systems. To address them is not only a scientific challenge, but – viewed in retrospect - also involves special difficulties. An analogy may help to put the matter into perspective: the traditional disciplinary researcher may be compared to a miner cutting tunnels through deep and difficult geological strata in order to reach a vein of valuable minerals. In contrast, the present type of research operates in the socio-technical and socio-economic area and may be compared to hacking a path through a dense jungle of a complex world and fighting against opinions, preconceptions and biases. And, just to complicate the situation still further, this is a jungle of whose existence most of its denizens are not even aware (similar in Abbott, 1999).

The research tasks are reviewed below and the extent to which they were satisfactorily accomplished is critically reviewed. They were:

1. *To develop an appropriate methodology aiming to analyze the actions and interactions of the stakeholders.*

   The methodology developed (chapter 4) allows an overall picture of these interactions to be gained. It consists of a catalog of behavioral rules which is discussed and further developed in a participatory process. These rules are then implemented in a computer model. It allows the user to simulate the development of relevant variables of a utility over the last 100 years. Moreover, scenarios of future developments can be simulated. The methodology is an effective way of addressing the behavior of stakeholders, at least in part. On the basis of this overview, it leaves enough room for refinements in order to allow more interesting aspects of the interactions to be discovered.

2. *To provide a tool to structure the discussion of the relevance of stakeholder influences (among participants such as engineers, sociologists, economists and politicians).*

   The rules consist of easy-to-understand "if – then" statements. Together with the computer model, which visually demonstrates the effects of the rules, they are a useful way of guiding and structuring the discussion. Specifically, they allow professional boundaries to be bridged because the rules can also be understood by stakeholders with a different professional background or by those not involved with these questions on a daily basis.

3. *To specify the behavior of stakeholders, their tasks, incentives and strategies. The effects of this behavior and of good engineering practice are to be highlighted.*

   Characteristic patterns of stakeholder behavior are highlighted by describing tasks, goals, strategies and specific rules of behavior and interaction (chapter 5). However, the description cannot provide more than an initial framework of behavior. In general, human behavior is too complex to be described in a single model. Every model must thus focus on specific aspects. The current model focuses on specific capacity-building behavior (utility, engineer), but places less emphasis on the thinking habits or the behavior of politicians and consumers.

   The effects of the behavioral rules on the development of the utility are examined in different scenario simulations (chapter 5 and 6). Traditional rules and best practice in engineering lead to a large static infrastructure, sufficient capacity reserves and supply-oriented worst-case concepts.

4. *To gain a better understanding of the observed phenomena*[2] *and of the reasons why the relevant systems have developed in a specific way.*

   The observed phenomena are comprehensible in the light of the interests of the stakeholders involved and of existing regulations and expectations (see also next section 7.4). The process of finding the rules, developing the model and performing scenarios helped considerably to improve this understanding. Also, awareness of such phenomena increased among the stakeholders who participated in the project. It is nevertheless important to further communicate these findings to more people involved in the water supply business. Currently, an aversion can still be observed to specifically addressing this taboo topic (private interests, see section 7.4).

5. *To provide a tool for simulating scenarios of future developments as well as the effects of stakeholder behavior.*

   The model allows the development of the utility to be simulated in retrospect (chapter 5). Similarly, it enables the user to simulate scenarios of possible future developments (chapter 6). Different strategies can be assigned to the stakeholders in the model. The simulations allow the effect of the changed rules to be discussed. Such changes in strategies greatly affect the development of the technical and financial variables of the utility.

6. *To identify possible ways of designing and operating water supply systems which increase flexibility and adaptability.*

   Three different strategies were explored (chapter 6). One of them is based on partial demand-side management (DSM). DSM emphasizes demand management and conservation as potential alternatives to increasingly expensive new capacity. If it is applied not to reduce consumption but to balance out its peaks, long-term benefits may be achieved. This possibility of influencing consumers offers more flexibility to the utility because it includes an additional degree of freedom. It also allows the utility to consider reducing otherwise necessary capacity reserves since consumption peaks are then brought more

[2] As discussed in chapters 1 and 2, an example of such phenomena is that in recent years supply capacity has been increased despite a declining demand trend. Moreover, new waterworks have been built even though water could have been supplied by a neighboring utility.

effectively "under control". This may satisfy the demands of political interest groups calling for lower water rates, privatization, less capital-intensive investments etc. The advantages and limitations of such a strategy would have to be effectively communicated to consumers and approved politically.

7. *To point out existing risks in current stakeholder behavior and propose management strategies or engineering guidelines which promote the increased flexibility of the utilities.*

   A risk of excessive supply security has been identified. Both technical and political problems may arise if capacity reserves grow too large. The past goals of increasing the security of supply by building large redundant infrastructure can be replaced today by the equally important goal of political freedom of action and efficient operating at full capacity. The concept of high supply security must be adjusted to the circumstances and other ways must be sought to ensure a reliable water supply (chapter 7.3). A strategy including demand-side management represents a good way of coping with the new challenges. The measures needed to implement such a strategy in concrete terms are described in section 7.5.

8. *To advocate and redirect further research by defining new research priorities in favor of more sustainable and flexible urban water-supply systems.*

   See sections 7.5 and 8.2.

Chapter 8

Conclusions

The objective of this research project was to contribute to the knowledge of the influence and effects of stakeholders on water supply systems. It also implied the acquisition of a deeper understanding of the interactions between the macroscopic dynamics of the system (e.g. observed capacity) and the microscopic interactions of its sub-systems (i.e. the stakeholders). The project finally aimed to point out existing risks of current stakeholder behavior and to identify possible ways of designing and operating water supply systems which increase flexibility and adaptability. New qualitative knowledge was obtained of the risks and opportunities involved in management concepts and engineering guidelines.

8.1 Conclusions

The main results of this research project can be outlined as follows:

- It is crucial to focus on the behavior of stakeholders (tasks, interests, interactions, strategies, rules) in order to acquire a better understanding of the past development of the infrastructure. Such greater insight forms the basis for the development of new supply concepts which are better adapted to future risks, uncertainties and opportunities.

- The methodology developed here provides a framework for successfully discovering and discussing the characteristic behavioral patterns of stakeholders. The three principal components of the methodology, namely the participatory process, the rule catalog and the computer model, can yield transparent, well-structured and comprehensible results. The rule-based approach (simple rules) is not necessarily the best but proved to be efficient, flexible and easy to understand by stakeholders.

- The behavioral complexity of reality can be captured to a sufficient degree by easy-to-understand "if–then" statements (rules). These rules allow the general pattern of the past development (capacity, cost, debt, etc.) of the utility to be modeled.

- Current experience shows that the integration of research methods from the social sciences (rule questionnaire, participatory process) and the applied sciences (computer model) is of great benefit. A good understanding of the concepts of engineering represents a crucial foundation for this integration.

- The simulation of different scenarios of possible future developments leads to a raised awareness of the advantages and deficits of existing strategies. A comparison of the performance of existing rules of behavior with altered ones can provide the foundation for discussing possible alternative supply strategies which are well adapted to today's situation. Because they are visualized by the model, the findings can be communicated well to decision-makers or other stakeholders.

- The traditional risk of insufficient security of supply must be augmented by considering the opposite risk of excessive security. This risk includes political blocking, technical problems and the inefficient supply of water to consumers.
- In the light of such a risk, the strategic and operational flexibility of a utility may be enhanced by introducing demand-side management. Although such a concept may lead to long-term benefits, it will also be necessary to address any short-term drawbacks. Nevertheless, it is recommended that a shift from supply to demand-oriented supply concepts be considered.
- Existing regulations and incentives should be reworked, as they inhibit the ability of utilities to improve their flexibility and performance.

8.2 Outlook

In addition to the measures proposed in the previous chapter, further research is suggested:

- *Use model.* The existing model should be further implemented together with the stakeholders involved in the round table. Not all information offered by the model has yet been gleaned. Several further rounds of simulation could be performed, some of them together with individual stakeholders in front of the computer. Their reactions would then be immediately visible. The various scenarios could also be formulated by the utility managers in order to relate to their needs.
- *Different stakeholders.* The model and its results should be discussed with different stakeholders from the same water utility. Different participants may see the "world" in diverse ways. The sensitivity of the stakeholders' perceptions would then be addressed. In addition, more stakeholders (e.g. fire department, politicians) could also be included.
- *Different utility.* The model should be validated with different utilities (and different stakeholders). The whole process should be repeated in order to evaluate whether different rule sets may be derived.
- *Different background.* Scientists with different professional backgrounds may be involved in order to include diverse viewpoints in the model.
- *Political behavior.* The behavior of political stakeholders should be further examined. This may be done by an expert from the field of social or politico-economic science, who could address the topic and refine the model.
- *Game theory.* Game theory (Von Neumann and Morgenstern, 1944) is a concept which may offer further insights into the interactions and behavior of stakeholders. This research method was neither discussed nor pursued further in this dissertation. However, it may provide a useful alternative approach to the tasks outlined here and will therefore be mentioned in brief. Game theory provides general mathematical techniques for analyzing situations in which two or more individuals make decisions that will influence their mutual welfare. To explore the present topic with economic game theory may offer an interesting alternative approach. In addition to the rule catalog, utility functions would then also have to be assigned to the stakeholders.

Further research may also be directed toward acquiring a deeper understanding of the reasons for the following aphorism which was already placed at the beginning of this thesis:

> *It is not because change is difficult that we shy away from tackling it.*
> *Change is difficult because we shy away from tackling it.*
> (Lucius Annaeus Seneca, 4 BC – 65 AD)

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Appendix A

Preliminary Model

Thc preliminary model resulted from the process to analze the current water supply system. It is an initial model, providing the basis of thought for the developed computer model. The next page depicts the system as an overview. The following pages of this appendix reflect the processes, which are executed by each stakeholder or domain object. They are linked with each other and depict the "zoom in" view of the whole system. See next page.

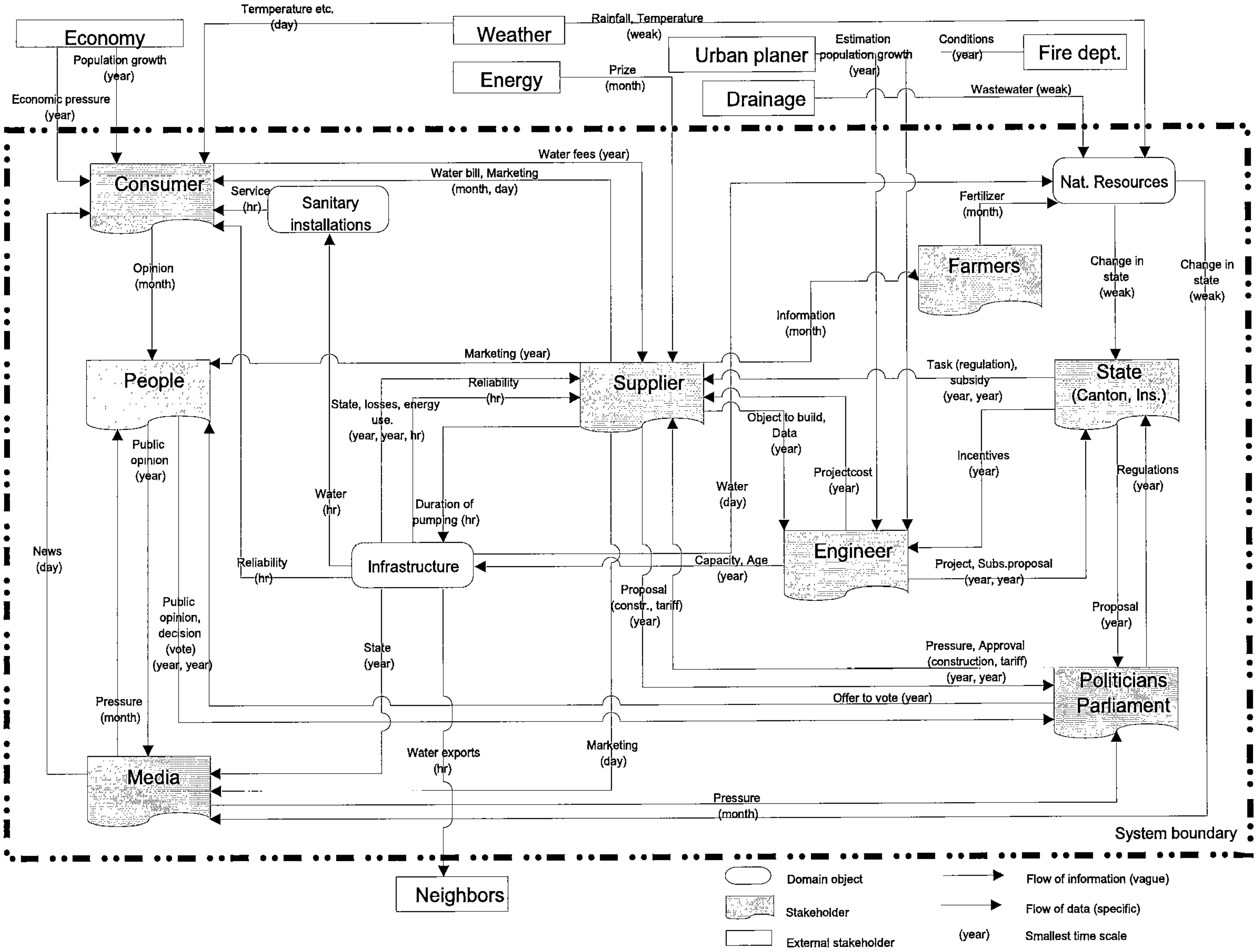

Figure A.1: System.

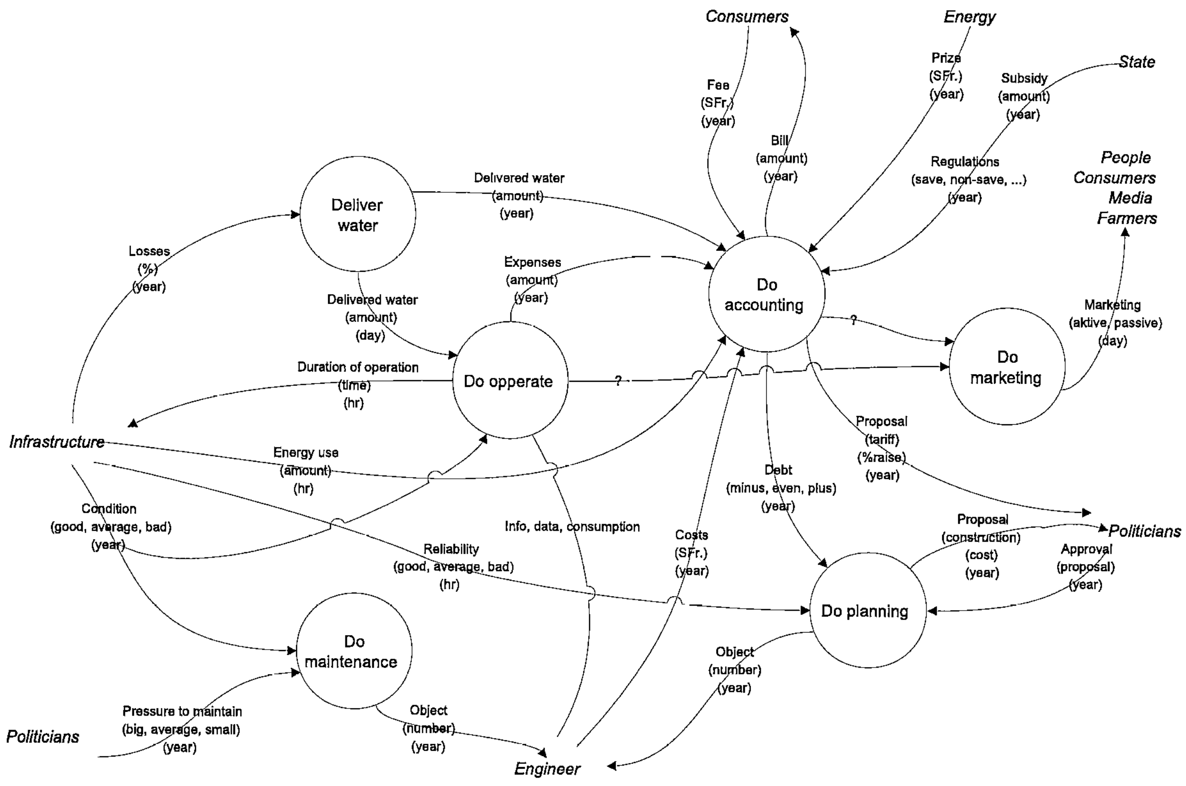

Figure A.2: Processes of supplier.

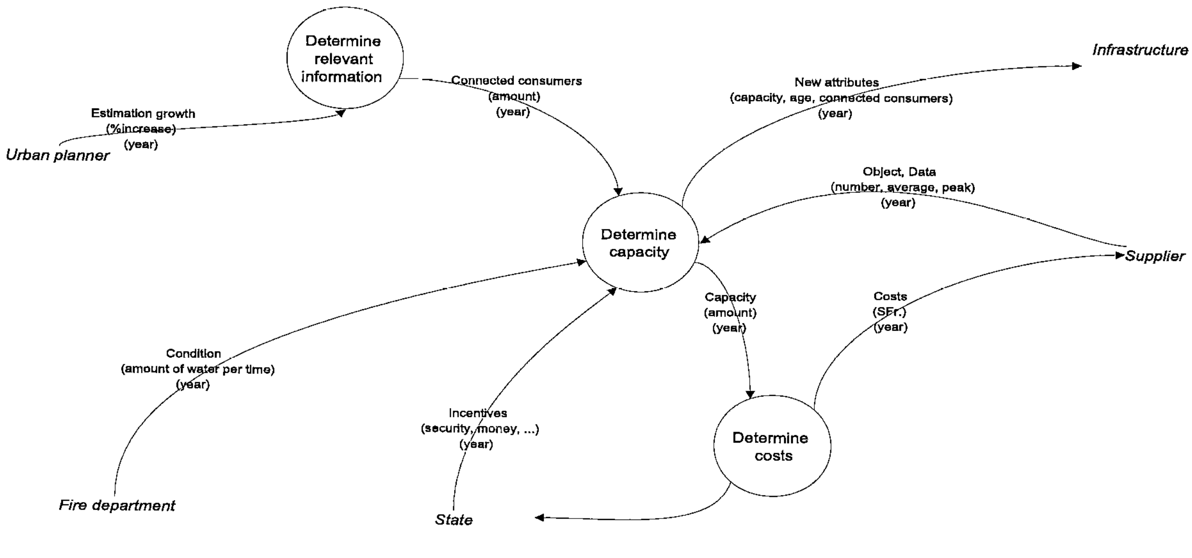

Figure A.3: Processes of engenieer.

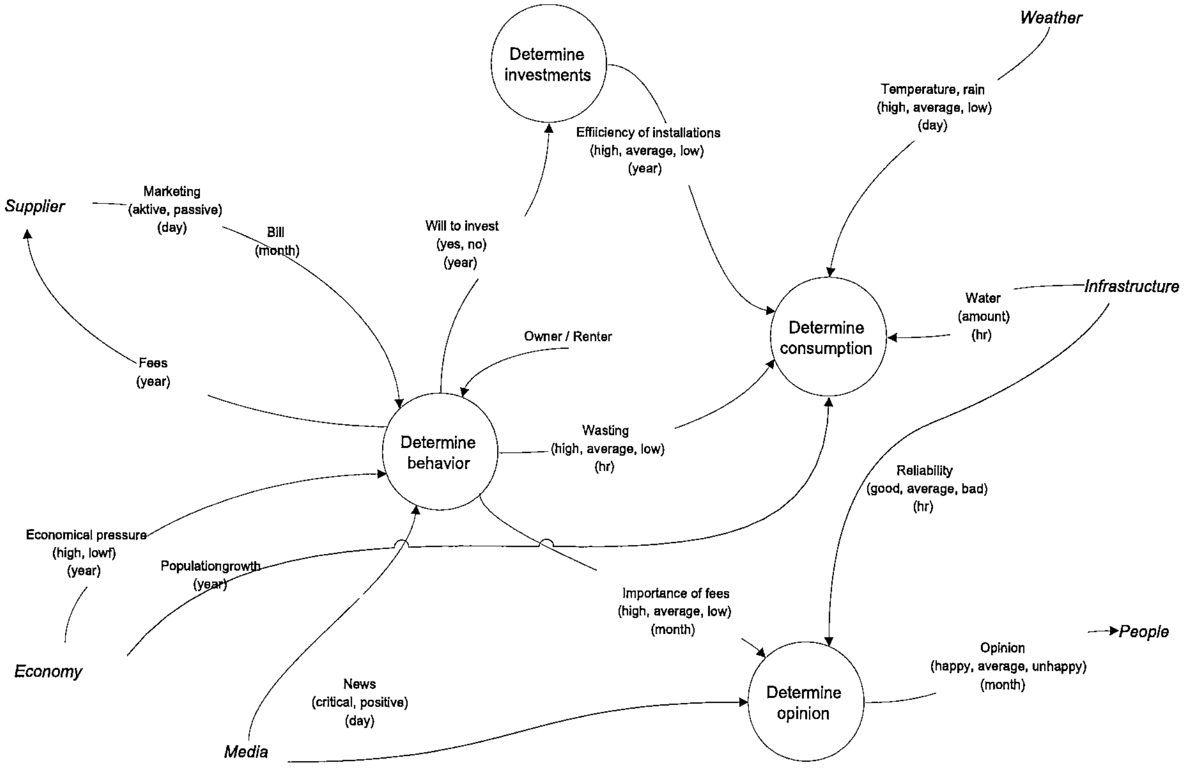

Figure A.4: *Processes of consumers.*

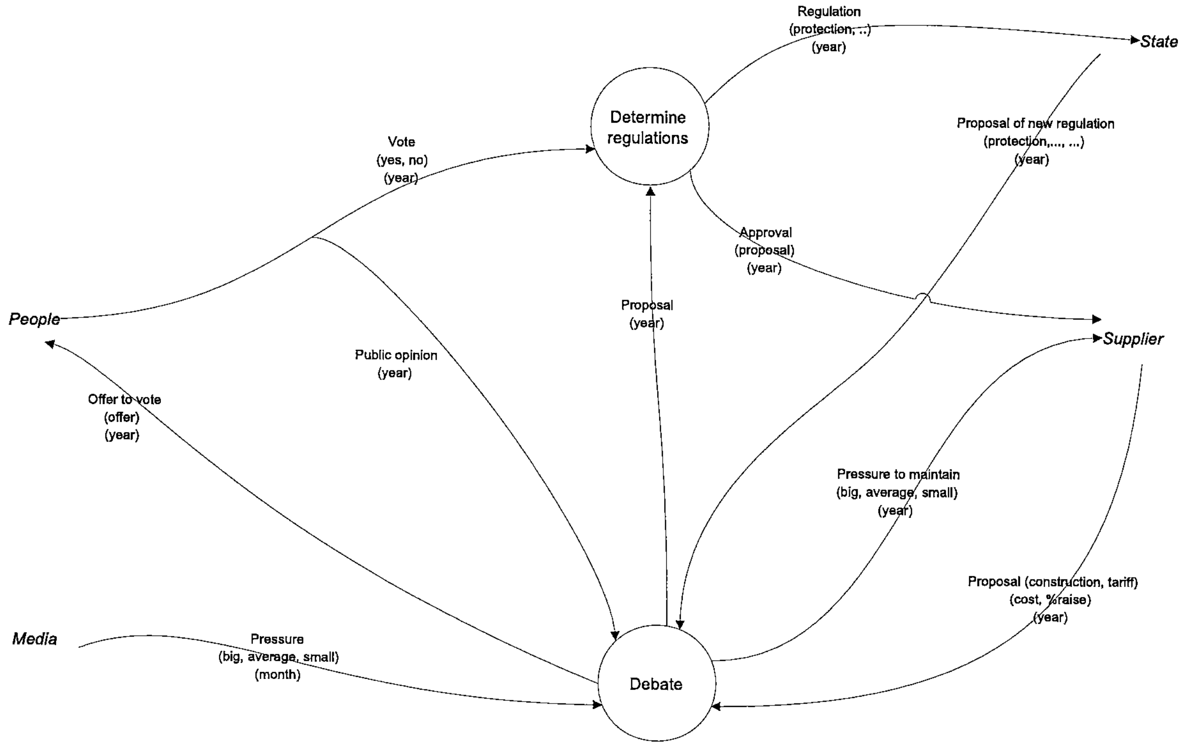

Figure A.5: *Processes of politicians.*

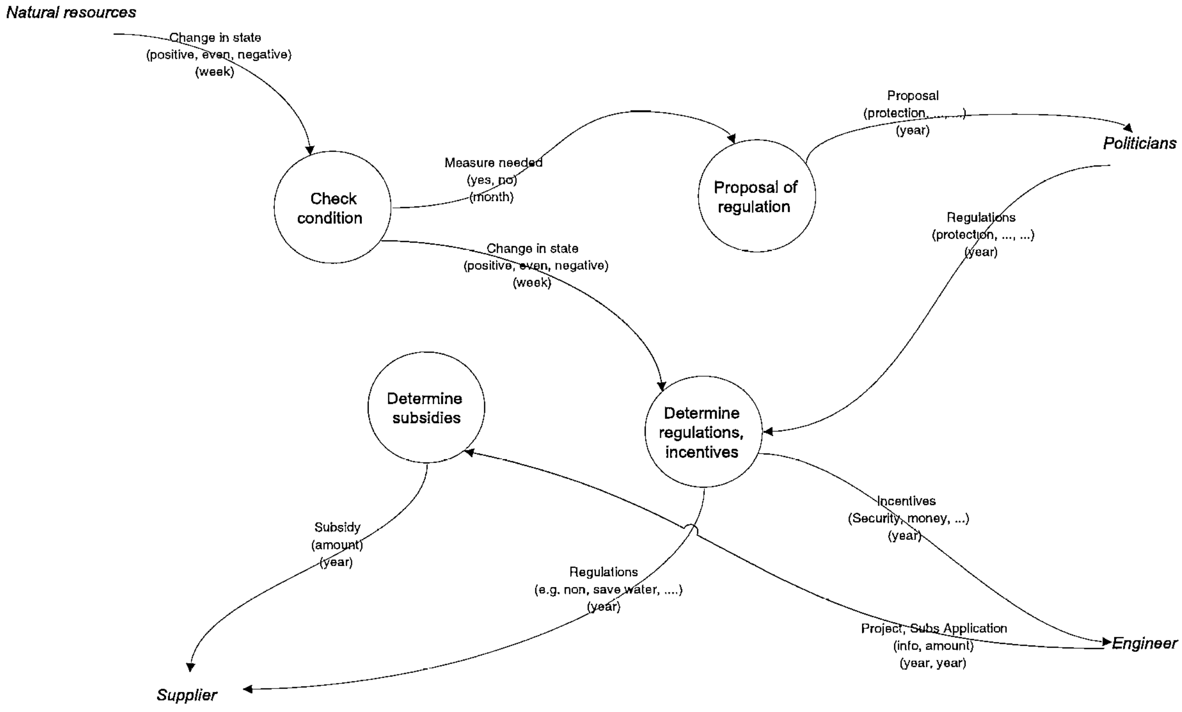

Figure A.6: *Processes of state.*

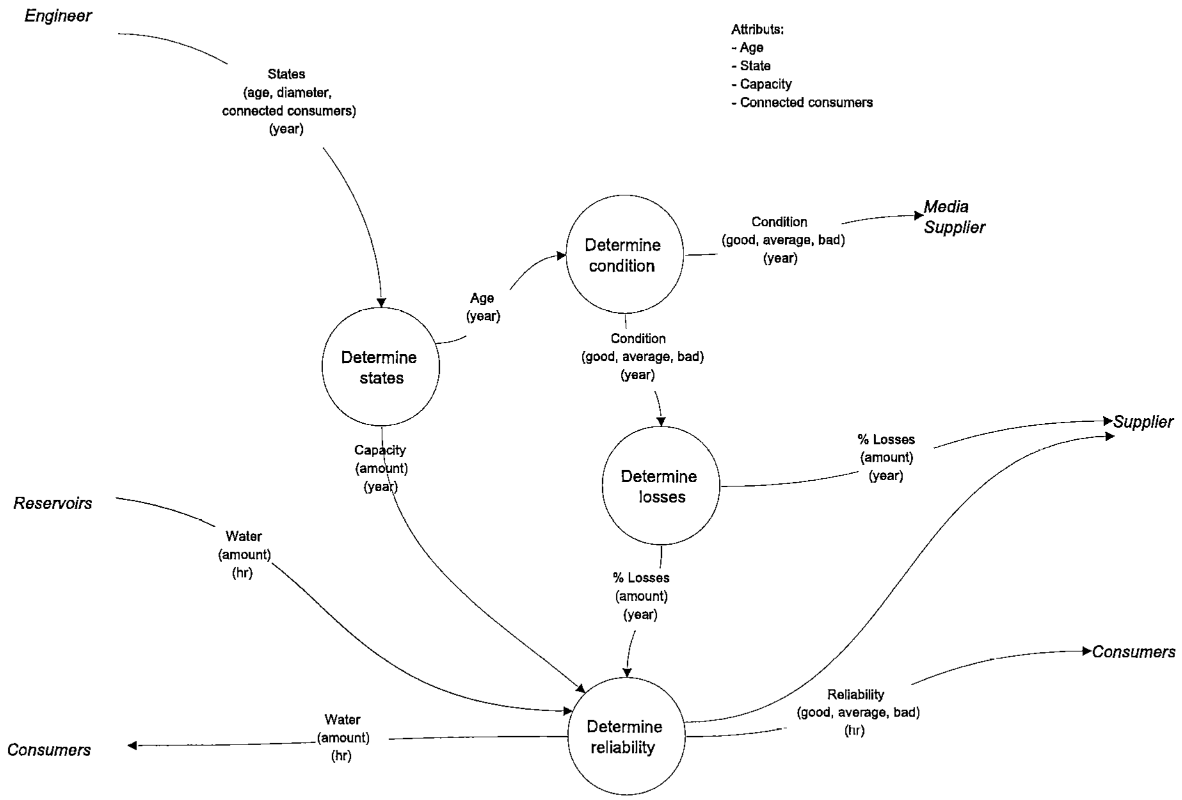

Figure A.7: *Processes of pipe mains.*

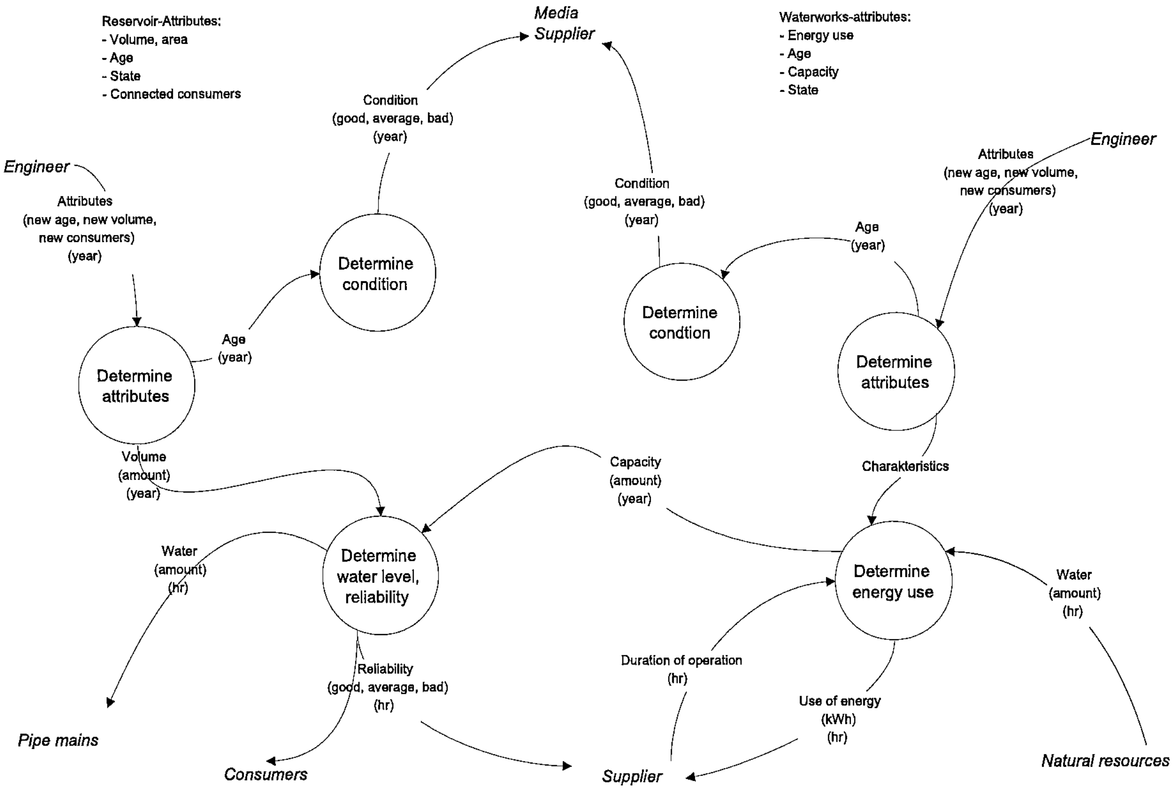

Figure A.8: Processes of waterworks and reservoirs.

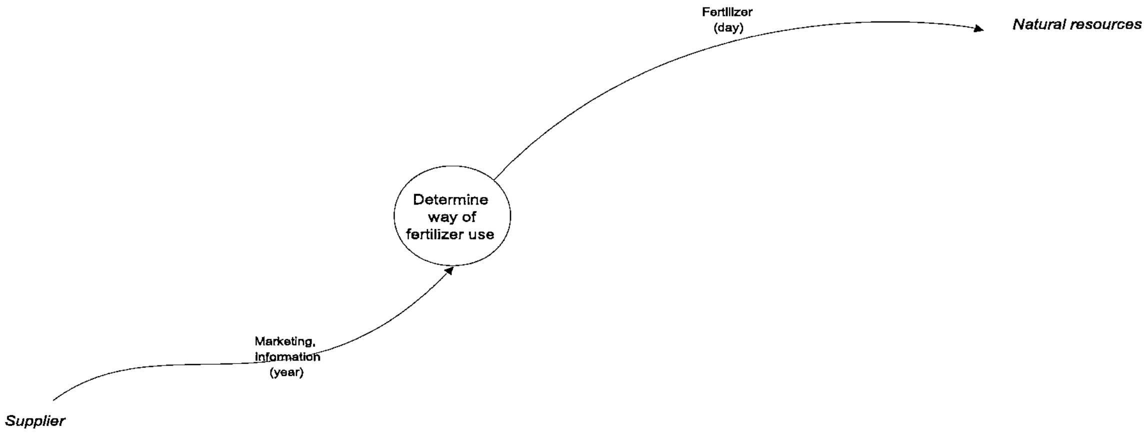

Figure A.9: Processes of farmers.

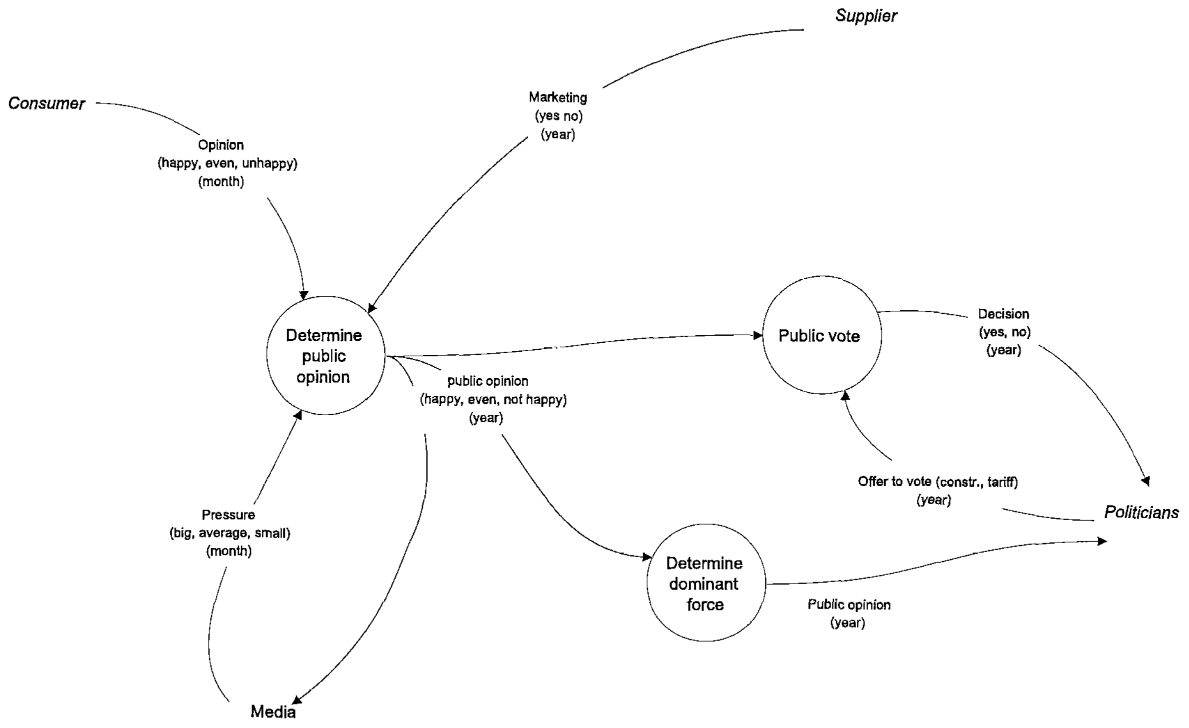

Figure A.10: Processes of people.

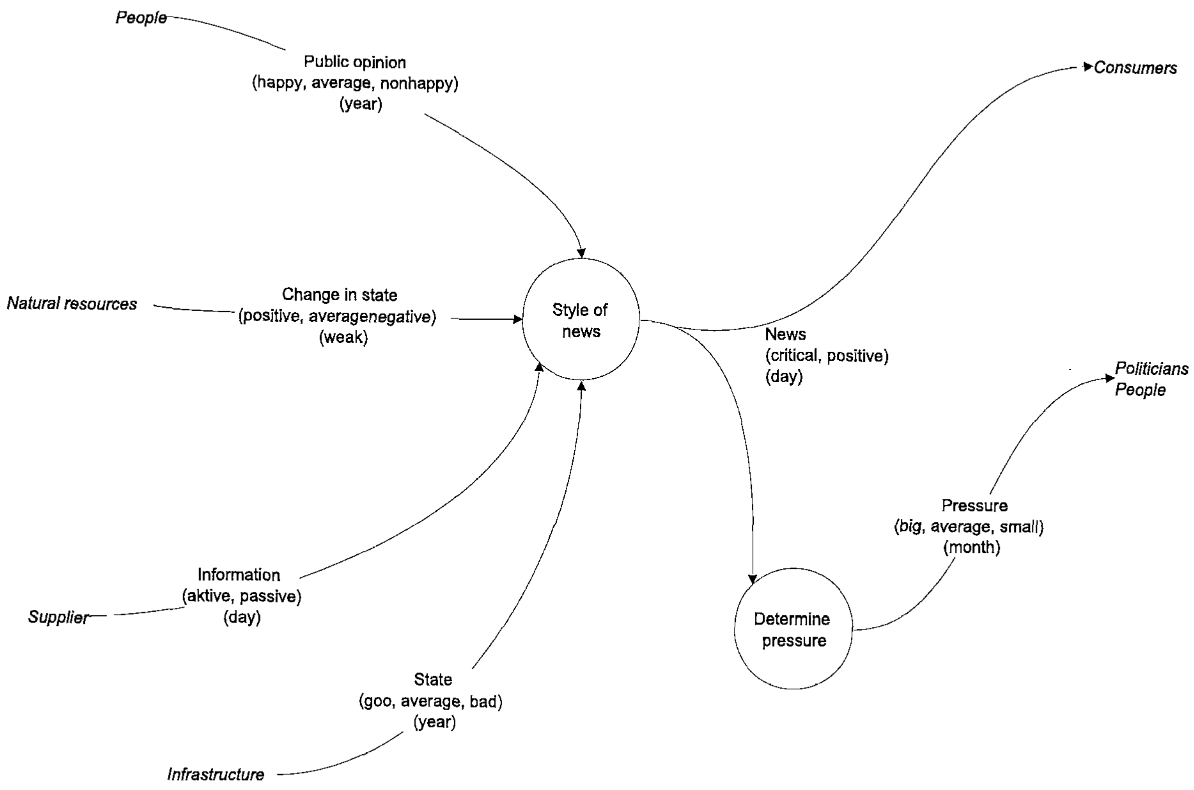

Figure A.11: Processes of media.

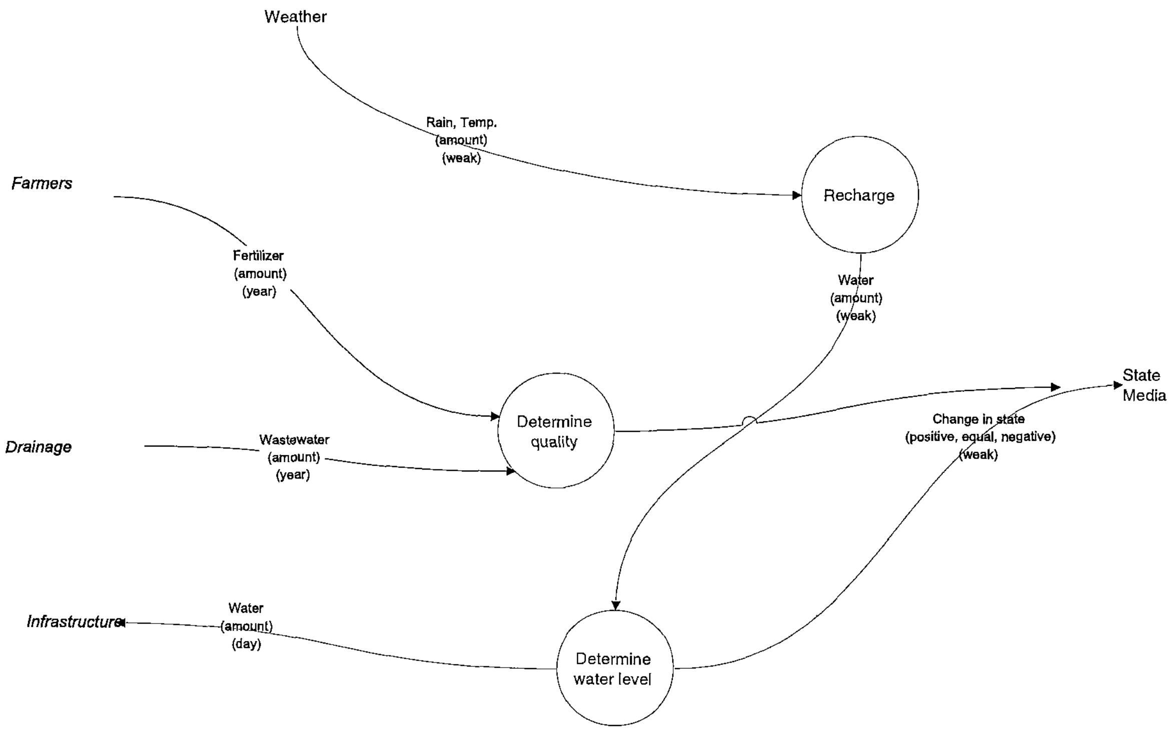

Figure A.12: Processes of natural resources.

Appendix B

Rule Catalog

B.1 Characterization of utility

B.1.1 Director

Table B.1: Task 1: Check infrastructure proposals.

Description in brief	Agreed? yes	partly	no
Past strategy: If a proposal is made by the utility chief engineer to adapt infrastructure (waterworks, reservoirs), then the proposal is supported and forwarded to the city councillor. As the adaptation infrastructure has priority, an increase in water tariffs may have to be accepted (source: discussion).	☒	☐	☐
Present strategy: If the infrastructure proposal is "urgent" and the reserve account (or result if before 1986) is positive, then support proposal and submit it to city councillor. If the reserve account (or the result if before 1986) is negative however, support the proposal (since it is urgent) but influence demand (demand side management) for the next 5 years (source: discussion).	☒	☐	☐
Present strategy: If urgency of proposal is normal, then reject it (no matter the financial situation). Wait until it gets urgent enough to accept it (source: discussion).	☒	☐	☐
Present strategy: If a proposal to decrease capacity is made, then approve it. Further approval by politicians is not necessary (source: assumption).	☒	☐	☐

Table B.2: Task 2: Check whether new tariff is needed.

Description in brief	Agreed? yes	partly	no
Until 1985: If the result of the utility is more negative than 15% of the turnover, then determine a new water tariff and submit it as "urgent" to the city councillor. If the result is less than zero, then determine a new water tariff and submit it as "not-urgent" to the city councillor (source: discussion).	☒	☐	☐

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Table B.2: *continued*

Description in brief	Agreed? yes partly no
As of 1986: If the reserve account is more negative than 15% of the expenses, then determine a new water tariff urgently (aside of enforcing savings, which is not included in the model). If the reserve account is more negative than half of 15% of the expenses, then determine a new water tariff with normal urgency (source: assumption).	☒ ☐ ☐
As of 1986: If the reserve account is greater than 15% of the turnover (income), then reduce the current water tariff with normal urgency (source: assumption).	☒ ☐ ☐

Table B.3: Task 3: Determine new water tariff.

Description in brief	Agreed? yes partly no
If a new water tariff is needed, then give an order to the head of finances to update the long-term financial plan, resulting in an estimated expense plan, which needs to be covered by the new tariff (source: discussion).	☒ ☐ ☐
If defining a new tariff based on the needed turnover, then approximately 40% of the expected turnover shall be covered by the service fee, 60% by the quantity charge (water tariff) (source: Business report of utility, 1908 – 1996, discussion). Note: this split does not reflect real cost structure but is for political reasons.	☒ ☐ ☐
If a new water tariff is calculated, submit it to the city councillor for approval only if the tariff needs to be increased (source: discussion). If tariffs are decreased, no approval is required (assumed for simplicity, although would have to be approved by parliament).	☒ ☐ ☐

Table B.4: Task 4: Inform people (public relations).

Description in brief	Agreed? yes partly no
Present strategy: If demand side management is needed (see task 1), then influence consumers to reduce their peak demand. The average demand is not influenced, but may react on prices (price-elasticity, see section B.3) (source: discussion).	☒ ☐ ☐

B.1.2 Chief engineer

Table B.5: Task 1: Check capacity and age of waterworks.

Description in brief	Agreed? yes partly no
Check age of waterworks: If an existing waterworks is older than its expected life-span (approximately 50 years. Model assumption: no ongoing renovation), then renew it. When planning the renovation, then consideration is also given to adapting the total amount of capacity (maybe an overall increase is needed). The proposal to renovate the waterworks is submitted for approval to the director. The degree of urgency is "not-urgent" (source: discussion).	☒ ☐ ☐
If an existing waterworks is more than 20 years older than the expected life-span (e.g. because an earlier non-urgent renovation proposal was not accepted and it was considered, due to large capacity reserves, to shut the waterworks down), then the renewal has to be done urgently (source: observation, assumption).	☐ ☒ ☐
If total capacity – without the waterworks to be renewed – would be less than last years peak demand plus a minimum capacity reserve (5%), then an urgent renovation proposal is submitted (source: assumption).	☒ ☐ ☐
Check overall capacity: If the existing waterworks capacity is less than last years peak consumption plus a capacity reserve of 5%, then plan an increase of capacity and characterize the proposal "urgent" (source: assumption).	☐ ☒ ☐
Past strategy: If the existing waterworks capacity is less than last years peak consumption plus a desirable capacity reserve of 20%, then plan an increase of capacity and characterize the proposal "not-urgent" (source: discussion).	☒ ☐ ☐
Design rules: If waterworks are planned, then at least two independent waterworks (or connections to neighboring utilities) are required (source: discussion).	☒ ☐ ☐
If new capacity needs to be planned, then the planning horizon is approximately 20 years (assuming 3 waterworks. Source: discussion).	☒ ☐ ☐
Past strategy: If new capacity needs to be determined, then it is based on an estimation of future water demand. The future demand is estimated based on the development of the past demand. The size of the required capacity is estimated as follows (see figure. Source: discussion): • Calculate linear regression of all the annual maximum, daily consumption peaks since 1908 (a). • Move the regression line through the peak value (b). • Extrapolate the resulting line to the planning horizon (c). • The new capacity according to this estimation is required to be larger than last year's peak demand plus 20% reserve (of existing capacity).	☒ ☐ ☐

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Table B.5: *continued*

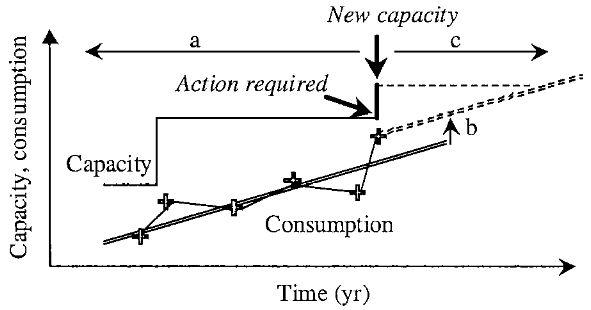
Description in brief	Agreed? yes	partly	no
 Present strategy: If capacity needs to be estimated, then it is done as follows (source: discussion): • Calculate linear regression of the last 10 data points of the annual average, daily consumption values (a). • Estimate the peak consumption by multiplying the average consumption by a factor of 1.5 (b). • Extrapolate the resulting regression line to the planning horizon (c). • The new capacity according to this estimation is required to be larger than last year's peak demand plus 5% reserve.	☒	☐	☐
If new capacity needs to be built, then the needs are discussed with the construction engineer, and some refinements are made based upon this discussion (source: discussion).	☒	☐	☐
If capacity needs to be increased, then the additional capacity gets built on the waterworks with the smallest capacity (source: model assumption).	☐	☒	☐
If a waterworks is less than 25 years old when getting expanded or renewed, then its age will not be set to 0 (source: model assumption).	☐	☒	☐
Past strategy: If the estimated capacity (according to the planning proceedure) is lower than the existing one, then capacity does not get decreased, but is kept at the existing level (source: discussion).	☒	☐	☐
Present strategy: If capacity needs to be increased, then consider the loads of existing waterworks. If a waterworks with only half the load (50%) exists, then increase the load of this waterworks to 100% (source: model assumption).	☐	☒	☐
Present strategy: If capacity needs to be decreased, then a part (50%) or the whole (100%) waterworks can be shut down. Only if the amount to be reduced is clearly larger than the whole waterworks capacity, does the whole waterworks get shut down (factor 1.1 in order to prevent stupid shutdowns). If the amount to be reduced is larger than 50% of the waterworks capacity, then the load of the waterworks gets reduced to 50%. If the load of the existing waterworks is already down to 50%, then it gets shut down (only 100%, 50% or shut down possible) (source: assumption).	☐	☒	☐
Present strategy: If the amount to be reduced is less than half of the waterworks with the smallest capacity, then no reduction is possible. Source: assumption).	☐	☒	☐

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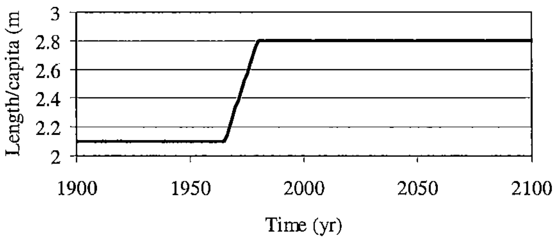
Table B.5: *continued*

Description in brief	Agreed?		
	yes	partly	no
Present strategy: If capacity needs to be increased and the number of waterworks is less than 3 as a result of an earlier shut down, then increase capacity by building a new waterworks (source: assumption).	☐	☒	☐
If an adaptation of capacity or renovation of a waterworks is proposed, then the proposal is submitted to the utility director (source: discussion).	☒	☐	☐
If the utility director (and the politicians) accept the proposal, then the construction firm can start construction.	☒	☐	☐

Table B.6: Task 2: Check pipe net size.

Description in brief	Agreed?		
	yes	partly	no
If the population of the city grows, then the total length of pipe mains grows as well. The specific length per inhabitant is assumed according to the figure below. The specific length per inhabitant increases around 1970. At that time, ring mains were introduced and the population decreased. If the population size of the delivered area decreases as a result of decreasing population density, then the pipes are left in the ground nevertheless (source: Documentation of utility, 1993, discussion).	☒	☐	☐



If new pipes are planned, then they are constructed in the same year without delay. As a result of this simplifying model assumption, the development of the net is modeled slightly too early (this assumption accelerates the speed of the model significantly. Source: model assumption).	☐	☒	☐
If new pipes are designed, then the design is based on a planning horizon of about 50 years (source: discussion).	☒	☐	☐
If new pipes are designed, then the shape of the diameter distribution remains similar to the one at the initial year 1908. However, as more water is consumed per inhabitant, the distribution shifts towards larger pipe diameters. For the description of the determination of the diameters of new pipes, see section B.6.3 on page 154 (source: assumption, observation).	☒	☐	☐

Table B.7: Task 3: Check age of individual pipes.

Description in brief	Agreed? yes partly no
There are three reasons why an existing pipe needs to be replaced: • a) Replacement due to bad condition from aging, forced sometimes through pipes failures (breaks). • b) Replacement in order to increase the existing diameter if the pipe is a bottleneck (maximal allowable pipe velocity 2-3 m/s). • c) Replacement just because it is convenient since a road is already under construction for other pipe work (electricity, gas, etc.). In the model, the last two reasons are ignored (since they could not be implemented in the current model setting).	☐ ☒ ☐
If the age of the pipe exceeds its expected life-span (which is determined in the model when creating the pipe, see section B.6.3 on page 154), then the pipe gets replaced, no matter the financial situation of the utility (as it is compulsory for the system).	☒ ☐ ☐
If the annual budgeted amount of pipe renewals is reached, then no more pipes are replaced that year. An average renewal rate of somewhat above 1.5% is common (source: observation).	☒ ☐ ☐

Table B.8: Task 4: Check reservoirs.

Description in brief	Agreed? yes partly no
Generally, the water stored in reservoirs provides the pressure for the network and covers the daily fluctuations in demand including the reserve for fire fighting. The needed storage volume corresponds generally to a daily average demand, but in large cities, rather less volume is needed. There are two reasons to manipulate the reservoirs: the replacement of existing, old reservoirs, and the adaptation of the total volume to the demand development (new reservoirs. Source: discussion).	☒ ☐ ☐
Check age of reservoirs: If an existing reservoir is older than its expected life-span, then renew it. When considering renewing a reservoir, then don't just renew this specific reservoir, but consider to adapt the total amount of reservoir volumes (maybe an overall increase is needed). The renovation proposal is, in general, not urgent (source: discussion).	☒ ☐ ☐
If the age of a reservoir exceeds its expected life-span by 20 years (e.g. because an earlier non-urgent renovation proposal was not accepted), then the renewal has to be done urgently (source: assumption).	☒ ☐ ☐
If the overall amount of reservoir volume – without the specific reservoir to be renewed – would be less than the minimum required reservoir volume (60% of average consumption), then an urgent renovation proposal is submitted (source: discussion).	☒ ☐ ☐

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Table B.8: *continued*

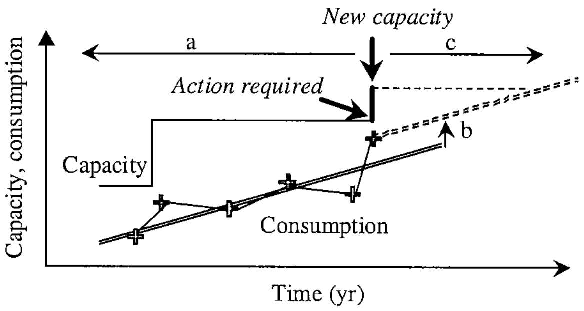
Description in brief	Agreed? yes	partly	no
Present strategy: If the total amount of reservoir volume – without the specific reservoir to be renewed – is larger than the desired reservoir volume (80% of average consumption) and if the general consumption trend for the last 10 years is decreasing, then shut the reservoir down (source: assumption).	☐	☒	☐
Check overall reservoir volume: If the existing volume is less than 60% of last year's average consumption, then plan an increase of volume and propose it urgently (source: discussion).	☒	☐	☐
If the existing volume is less than 80% of last year's average consumption, then plan an increase of volume with normal urgency (source: discussion, assumption).	☐	☒	☐
Design rules: If a reservoir gets built, then its expected life-span is 50 years. Assuming about 10 reservoirs, the planning horizon is assumed to be 5 years (model assumption, every 5 years another reservoir is built. In reality, it depends on the location of the reservoir. Source: discussion, assumption).	☐	☒	☐
Past strategy: If the volume needs to be increased, its value is estimated as follows (source: discussion): • Calculate linear regression of all the annual average, daily consumption peaks since 1908 (a). • Extrapolate the resulting line to the planning horizon of 5 years (item b not used). • The new volume according to this estimation is required to be at least 80% of last year's average consumption. 	☒	☐	☐
Present strategy: If the volume needs to be increased, its value is estimated according to the above rule, but taking only the last 10 years into account if calculating the regression of the average consumption (source: discussion).	☒	☐	☐
If a new reservoir is designed, then it gets discussed with the construction engineer, and some refinements are made based upon this discussion (source: discussion).	☒	☐	☐
If the reservoir volume needs to be increased, then a new reservoir is built (at an optimal place) and not an existing reservoir enlarged (source: model assumption).	☐	☒	☐

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Table B.8: *continued*

Description in brief	Agreed? yes	partly	no
If the age of a reservoir is less than 25 years when being renewed, then the age after the renovation is not set to zero (source: model assumption).	☐	☒	☐
If a new reservoir proposal is established, then it gets submitted to the director (source: discussion).	☒	☐	☐
If the director (and his politicial superiors) approve the proposal, then the contract to build the new reservoir is given to the constructing engieering firm (source: discussion).	☒	☐	☐
If a reservoir which should be renewed (not urgently) does not get the approval for renewal, then shut the reservoir down (source: assumption).	☐	☒	☐

Table B.9: Task 5: Design infrastructure for security, machines, control, etc.

Description in brief	Agreed? yes	partly	no
Every year: Invest approximately 3% of the total initial net value of the waterworks for their maintenance and technical upgrade. Similarly, 3% of the total initial net value of the existing reservoirs is invested in maintenance and technical upgrade (source: observation).	☒	☐	☐
Past strategy: If the year is between 1980 and 2000, then a ring is built, requiring special investments for pipes. If no waterworks are built, then invest 20% of gross investments of the last 10 years (the amount normally spent on waterworks) additionally on pipes (source: observation, assumption).	☐	☒	☐
If, during the year, it is seen that the financial result will be positive and the debts are not larger than the book value of the infrastructure, then extra investments are made. In that case, if the reserve account is >= 0, then 80% of the result is reinvested, 20% of the result is put in the reserve account (or returned to the city before 1986). If the reserve account is negative, then 80% of the result is used to replenish the reserve account, and only 20% is reinvested (source: observation and assumption).	☒	☐	☐

Table B.10: Task 6: Determine water use by consumers.

<table>
<tr><th rowspan="2">Description in brief</th><th colspan="3">Agreed?</th></tr>
<tr><th>yes</th><th>partly</th><th>no</th></tr>
<tr><td>If water is consumed, then the consumption is attributable to the following consumers (source: observations):
• 65% by town consumers (people 45% and industry 20%)
• 20% partners
• 15% fountains, losses, own requirements.</td><td>☒</td><td>☐</td><td>☐</td></tr>
</table>

B.1.3 Head of finances

Table B.11: Task 1: Prepare investment statement.

Description in brief	Agreed? yes	partly	no
If investment costs arise, then they are divided into 3 categories: waterworks, reservoirs and pipes. All other investments are included in these categories (source: model assumption).	☒	☐	☐
If bills are received, then they are paid in the same year without significant delay (source: discussion).	☒	☐	☐
If investments are made, then the net investments are calculated from gross investments minus subsidies and connection fees, respectively (source: discussion).	☒	☐	☐
If the new accounting strategy is operative (after 1986), then connection fees are included in the accounting for investments. Before 1986, connection fees were part of the profit and loss accounting (source: observation).	☒	☐	☐

Table B.12: Task 2: Prepare profit and loss statement.

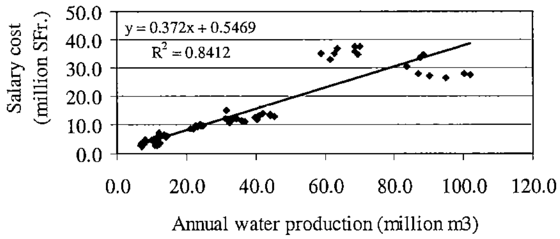
Description in brief	Agreed? yes	partly	no
Every year, salaries are paid. They are dependent on the size of the annual water production (size of utility) and the services delivered by the utility. Total cost for salaries is estimated by linear regression of the salary cost (real by 1996) versus annual water production of ten similar utilities and adapted to the depicted utility (factor 1.5) (source: observation). 	☒	☐	☐
Every year, material costs are paid (chemicals, power, cars, etc.). These costs are dependent on the size of the infrastructure and the amount of services the utility provides. They can be estimated by comparing the material cost of 10 different utilities and deriving a function of the costs versus water production as below (source: observation).	☒	☐	☐

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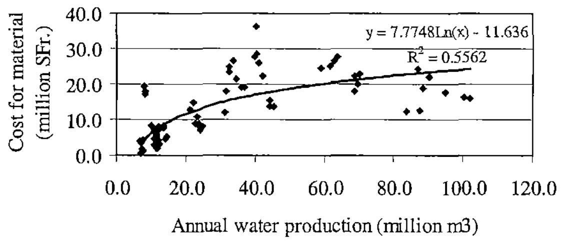
Table B.12: *continued*

Description in brief	Agreed? yes	partly	no



Every year, interest on debt is paid. The interest rate is fixed by the state (see section B.5 on page 147).	⊠	☐	☐
Every year, the cost of the infrastructure is depreciated. Depreciation is linear and based on the initial net value of the building. The initial net value does not get adjusted for inflation. All infrastructure costs are depreciated with approximately the same rate. The rate and the procedure to depreciate is fixed by the state (source: observation, discussion).	⊠	☐	☐
Begining of depreciation (source: observation): • Waterworks/reservoirs: depreciation begins at the first year of the construction phase. In the model, for simplicity, the planning phase is part of the construction phase). • Pipes: depreciation begins at first year of planning/construction period. In the model, for simplicity, pipes are built in 1 year.	⊠	☐	☐
Every year, income is calculated. Income from the city (industry and people) is calculated by adding the product of water price times consumption, plus the product of service fee times number of house connections. It is approximately 75% of the total income. The rest of the income comes from partners, other services provided etc. This income-split staid constant over the past years (source: observation).	⊠	☐	☐

Table B.13: Task 3: Prepare balance sheet.

Description in brief	Agreed? yes	partly	no
If investments are made on existing infrastructure, then the book value of the infrastructure is increased by the amount of the net investment. Correspondingly, the new initial net value (needed for depreciation) is the new book value (source: discussion).	⊠	☐	☐
Up to 1971: If a profit or loss is realized, then it is transferred to the state. Profits or losses may not be carried forward (source: discussion).	⊠	☐	☐
Since 1972: If the book value is smaller than debts, then debts are repaid out of profits generated (source: discussion).	⊠	☐	☐

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Table B.13: *continued*

Description in brief	Agreed? yes partly no
Every year: If investments are made, then the needed bank capital is the investment minus depreciations (source: discussion, simplified).	☒ ☐ ☐
Since 1972: If the financial result is positive at the end of the year and the debt is not larger than the book value, then extra investments are made (this happens, of course, during the year in reality). In the case that the reserve account is larger than 0, then 80% of the result is reinvested (maintenance), 20% of the result is used to fill the reserve account (or return to the city before 1986). If the reserve account is negative, then 80% of the result is used to fill the reserve account, and only 20% is reinvested (source: discussion, assumption).	☐ ☒ ☐
Every year: Debt is the accumulation of needed bank capital less pay backs (source: discussion).	☒ ☐ ☐

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Table B.14: Task 4: Make finance plan.

Description in brief	Agreed? yes partly no
In practice, a finance plan is made periodically every year. In the model, if the director wants to increase the water tariff, only then a new finance plan is made. But if a new price is to be introduced, then the finance plan has to be up to date. Therefore, in the model, it is assumed to make a finance plan only when a new tariff will be introduced (source: assumption, discussion).	☒ ☐ ☐
If a finance plan is made in order to increase water tariffs (expenses larger than income), then the base for new tariffs is the current expenses, increased by 15% (source: assumption, observation).	☐ ☒ ☐
If a finance plan in made in order to decrease water tariffs (income larger than expenses), then the basis for new tariffs is the current income reduced by half (7.5%) of the increasing percentage (15%) (source: assumption).	☐ ☒ ☐

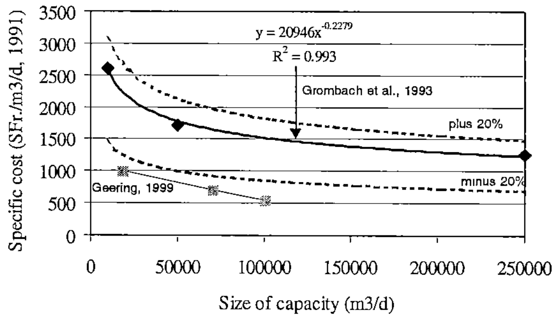
B.2 Characterization of constructing engineering firm

Table B.15: Task 1: Negotiate size and details of construction job.

Description in brief	Agreed? yes	partly	no
Past strategy: If a job order to build new capacity is received, then increase the proposed size by 10% as a result of discussions due to practicability (source: discussion).	☒	☐	☐
Present strategy: If a job order to build new capacity is received, then do not increase the proposed size anymore (source: discussion).	☒	☐	☐
Past strategy: If a new pipe is to be built (the diameter proposed by the utility), then round the proposed diameter up to the next common one on the market. The common diameters are: 50mm, 100, 150, 200, 250, 300, 450, 650, 850, 1000mm (source: discussion).	☒	☐	☐
Present strategy: If a new pipe is to be built with a proposed diameter, then round the proposed diameter down to the next common one on the market due to cost considerations (source: discussion).	☒	☐	☐

Table B.16: Task 2: Build new or adapt existing waterworks.

Description in brief	Agreed? yes	partly	no
If new capacity needs to be built (waterworks including pumping stations), then the costs are dependent upon the size and type of construction. The costs for lake water treatment plants (and pumping stations) can be estimated according to the figure below (source: Grombach et al., 1993; Geering, 1999).	☒	☐	☐



Past strategy: When costs are determined, then increase them by 20% as a result of no competition, a pressure to build new pumps and general perfectionism (upper dotted line in figure above) (source: discussion, assumption).	☒	☐	☐
Present strategy: When costs are determined, then reduce them by 20% as a result of competition and cost pressures on the construction industry. Furthermore, as treatment plants can be built in a more economical way (more compact, less volumes), costs can be reduced by another 30% (lower dotted line in figure above) (source: discussion).	☒	☐	☐

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Table B.16: *continued*

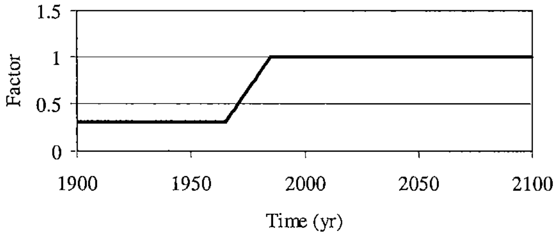
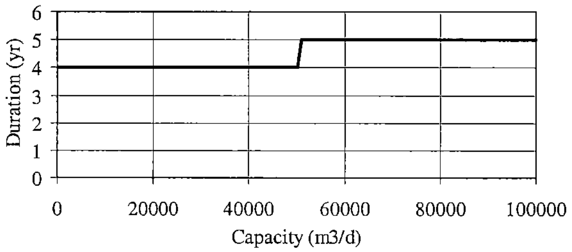
Description in brief	Agreed? yes partly no
When costs are determined, then the development of technology must be taken into account. The technological development is estimated in the figure below as a result of different effluent limits and technological processes compared to the reference year for costs (in 1991) (source: discussion, assumption based on Documentation of utility, 1993).  	☒ ☐ ☐
When costs are calculated, then inflation is included as fixed by the state (see section B.5 on page 147).	☒ ☐ ☐
If waterworks need to be built, then the duration for planning and construction can be assumed according to the figure below. Independently of the size of the planned waterworks, the planning phase (final project) requires approximately 2 years, the procedure for approval 1 year. The construction period is dependent on the size of the waterworks (source: discussion).  	☒ ☐ ☐
If a new waterworks is built, then its costs are split linearly during the whole planning and construction process (source: discussion, assumption).	☐ ☒ ☐
If an existing waterworks needs to be renovated, then the costs of renovation are approximately half the cost of a complete new waterworks (source: assumption). Note: Depends on situation, could be as expensive as new.	☐ ☒ ☐

Table B.17: Task 3: Build new or adapt existing reservoir.

Description in brief	Agreed? yes partly no
If new reservoirs need to be built, then the costs are dependent upon the size of the reservoir. The cost can be estimated according to the figure below (source: Grombach et al., 1993; Meier, 1991).	☒ ☐ ☐

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Table B.17: *continued*

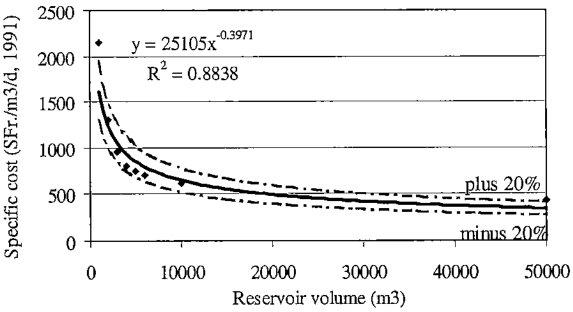
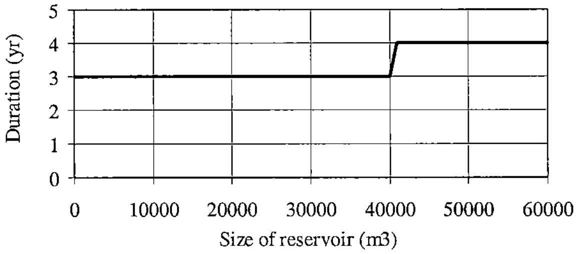
Description in brief	Agreed? yes	partly	no
			
Past strategy: When costs are determined, then increase them by 20% as a result of no competition, a great pressure to build new reservoirs and general perfectionism (upper dotted line in figure) (source: discussion, assumption).	☒	☐	☐
Present strategy: When costs are determined, then reduce them by 20% as a result of competition and cost pressures on the construction industry (lower dotted line in figure above) (source: discussion).	☒	☐	☐
When costs are calculated, then inflation is included as fixed by the state (see section B.5 on page 147).	☒	☐	☐
If reservoirs are built, then the duration for planning and construction can be assumed according to the figure below. Independently of the size of the planned reservoir, 1 year is needed for planning and approval of the final project, respectively. The construction period though is dependent on the size of the reservoir (source: discussion). 	☒	☐	☐
If a new reservoir is built, then the costs of the building can be assumed to be split linearly during the whole planning and construction process (source: discussion).	☒	☐	☐
If an existing reservoir needs to be renovated, then the cost of renovation is approximately half the cost of a complete new reservoir (source: assumption).	☒	☐	☐

Table B.18: Task 4: Build or replace existing pipes.

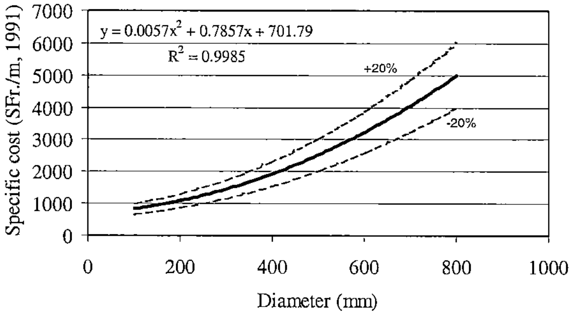
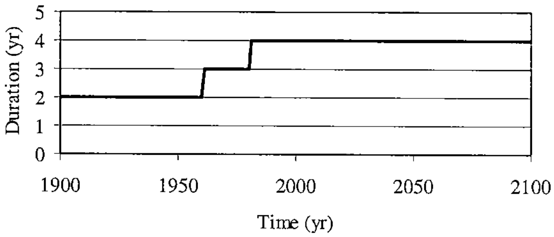
Description in brief	Agreed? yes partly no
If a new pipe is built, then its costs correspond to the figure below (source: data of local engineering firm, utility and Betschart, 1999). Special costs due to high traffic, special thickness of road, trams in the roads etc. are included in the pipe inflation index, see section B.5 on page 147). 	☒ ☐ ☐
Past strategy: When costs are determined, then increase them by 20% as a result of no competition and general perfectionism (upper dotted line in figure) (source: discussion, assumption).	☐ ☒ ☐
Present strategy: When costs are determined, then reduce them by 20% as a result of competition and cost pressures on the construction industry (lower dotted line in figure above) (source: discussion).	☒ ☐ ☐
If a new pipe is built, then its mean life-expectancy is dependent primarily on the material used, and distributed with a certain distribution (Trujillo Alvarez, 1995). In the model, a gaussian distribution with a standard deviation of 10 years is assumed. The following materials were used in different time periods (source: observation): • 1900 - 1964: Cast iron: An average life-expectancy of 80 years can be expected (Trujillo Alvarez, 1995). • 1965 - 1991: Ductile iron: An average life-expectancy of 40 years can be expected (source: discussed) • 1992 - 2200: Ductile iron pipes with exterior protection: An average life-expectancy of 100 years can be expected (source: discussion, assumption).	☒ ☐ ☐
If a new pipe is built, then the duration of the planning and construction period changes over time as a result of increasing traffic, other infrastructure, a more complicated planning procedure etc. (source: discussion): 	☒ ☐ ☐

Table B.19: Task 5: Build other infrastructure.

Description in brief	Agreed? yes	partly	no
Past strategy: When costs are determined, then increase them by 20% as a result of no competition and general perfectionism (source: discussion, assumption).	☒	☐	☐
Present strategy: When costs are determined, then reduce them by 20% as a result of competition and cost pressures on the construction industry (source: assumption).	☒	☐	☐

B.3 Characterization of consumers

Table B.20: Task 1: Define average consumption.

Description in brief	Agreed? yes partly no
Up to 1996: the average consumption is given and the data taken from the data base. The total amount is split up equally among all the consumers in the model (source: model assumption. Data-source: Documentation of utility, 1993; Business report of utility, 1996). After 1996 (scenario): the average consumption is defined using a rate of consumption change compared to the past year. Basic scenario: 0.0% (source: model assumption).	☒ ☐ ☐
If water is consumed, then the consumption reflects the total amount of water used by private people, small businesses, industry, partners, losses, fountains and own needs by the utility (source: observation).	☒ ☐ ☐
After 1996 (scenario): tariff increases may influence average consumption due to price elasticity (basic scenario: -0.0). Although consumers don't see prices, the public discussion may influence their behavior (source: assumption, based on experiences of other utilities).	☐ ☒ ☐

Table B.21: Task 2: Define maximum water consumption.

Description in brief	Agreed? yes partly no
Up to 1996: the maximum consumption is given and taken from a data base (source: Documentation of utility, 1993; Business report of utility, 1996). After 1996 (scenario): the maximum consumption is estimated using typical maximum/average ratios. Basic scenario: The ratio is randomly between 1.2 and 1.7. (source: Documentation of utility, 1993; Business report of utility, 1996, discussion).	☒ ☐ ☐
After 1996 (scenario): if consumers are motivated by the authorities to reduce the annual maximum, daily demand, then the ratio of peak to average consumption is reduced by 30% (basic scenario) (source: assumption, based on past experiences at other utilities, discussion).	☐ ☒ ☐

Table B.22: Task 3: Pay initial connection fees.

Description in brief	Agreed? yes partly no
If a new house is connected to the existing system, then connection fees are charged. The development of these fees in relation (%) to gross investments is as follows (source: Business report of utility, 1908 – 1996):	☒ ☐ ☐

continued on next page

Table B.22: *continued*

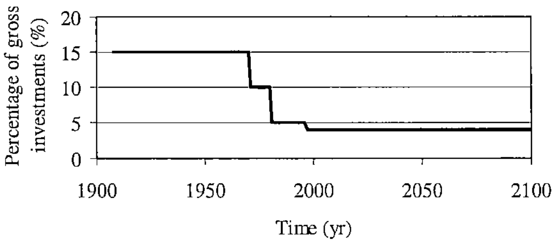
Description in brief	Agreed? yes partly no
	
After 1996 (scenario): the connection fees will continue to be at about 4% of gross investments (basic scenario. Source: discussion).	☒ ☐ ☐

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Table B.23: Task 4: Pay bill for consumed water.

Description in brief	Agreed? yes partly no
If water is consumed, then the costs are billed annually. The bill is based on two tariffs. It includes both a consumption dependent fee and a connection fee, which is based on the size of the water meter (source: Regulation of utility, 1989).	☒ ☐ ☐
If a water meter is installed, then its size is dependent on the amount of water used. Per person, a water meter of approximately 0.8 m^3/h is needed (adds up to about $3m^3/h$ for a family house). This portion staid approximately constant over the past years (source: Business report of utility, 1908 – 1996).	☒ ☐ ☐
When the water bill is determined, then the portion of total income payed by modeled consumers (sum of private use, small businesses, industry) is 75% of the total amount. The rest (25%) is paid by partners or is not accountable (losses, fountains etc.). This ratio stayed approximately constant over the past years (source: Business report of utility, 1908 – 1996).	☒ ☐ ☐
When the water bill is determined, then the portion of the total amount of water used by modeled consumers is 65%. Water consumption is attributable to the different types of consumers as follows (source: Business report of utility, 1908 – 1996): • Houses (normal consumption): 45% • Industry: 20% • Partners: 20% • Losses, measuring differences, fountains, fire department, own needs: 15%	☒ ☐ ☐

Table B.24: Task 5: Form opinion on quality and cost of service.

Description in brief	Agreed? yes partly no
If the financial pressure is less, then consumers are satisfied. Tariffs are then less important to consumers, so that a potential price rise would not be noticed (source: observation, assumption).	☐ ☒ ☐
If the financial pressure is high, then consumers are price-sensitive. If the water tariff is increased by the utility, consumers are "not-happy" for 3 years (source: assumption).	☐ ☒ ☐

B.4 Characterization of politicians

B.4.1 City councillor

Table B.25: Task 1: Check price proposals.

Description in brief	Agreed? yes partly no
If the proposal is urgent, then approve the new price and submit it to the parliament (source: required by law, discussion).	☒ ☐ ☐
If the proposal is not urgent, then approve the new price nevertheless, since the price increase is not proposed in order to make more profit but because the expenditures of the utility cannot be fuly paid any longer (source: assumption, partly discussed).	☐ ☒ ☐

Table B.26: Task 2: Check construction proposal.

Description in brief	Agreed? yes partly no
If the proposal is urgent, then it gets approved and submitted to the parliament (source: required by law, partly discussed).	☒ ☐ ☐
If the proposal is not urgent but the financial situation of the state is good (given), then approve it and submit it to the parliament (source: partly discussed).	☐ ☒ ☐
If the proposal is not urgent and the financial situation of the state is bad, then approve it if the financial state of the utility is good (reserve account ≥ 0), otherwise reject it (source: assumption, partly discussed).	☐ ☒ ☐

Table B.27: Task 3: Publish new tariff.

Description in brief	Agreed? yes partly no
If a new water tariff gets introduced, then communicate it to the consumers (source: discussion).	☒ ☐ ☐

B.4.2 Members of parliament

Table B.28: Task 1: Decide on tariff increase requests.

Description in brief	Agreed? yes	partly	no
If the price proposal is urgent, then it gets approved (source: required by law).	☒	☐	☐
If the price proposal is not urgent but the public opinion is good, then approve proposal (source: assumption, observation).	☐	☒	☐
If neither the proposal is urgent nor the public opinion good, then reject the proposal (source: assumption, observation, partly discussed).	☐	☒	☐

Table B.29: Task 2: Decide on construction requests.

Description in brief	Agreed? yes	partly	no
If the proposal is urgent, then approve it (source: required by law).	☒	☐	☐
If the proposal is not urgent, then approve it only if the public opinion is good (since new infrastructure enhances the chance for new tariff raises) (source: assumption).	☐	☒	☐

Table B.30: Task 3: Evaluate public opinion.

Description in brief	Agreed? yes	partly	no
If the majority (more than 50%) of the consumers are "satisfied", then the public opinion is good (source: assumption). Note: in reality, it is more likely that the public seems to be unhappy if 10% are unhappy.	☐	☒	☐

B.5 Characterization of state

Table B.31: Task 1: Pay subsidies to promote development.

Description in brief	Agreed? yes	partly	no
If investments are made, then the state (including the state-owned insurance company for buildings) subsidizes them in order to promote the development. The amount of subsidy in % of gross investments developed as shon in the figure (source: Business report of utility, 1908 – 1996). As future scenario, an average subsidy rate of 5% can be expected (source: discussion).	☒	☐	☐

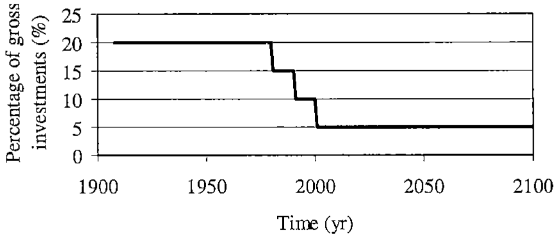


Table B.32: Task 2: Define accounting strategy.

Description in brief	Agreed? yes	partly	no
Up to 1971: Profit made by the utility has to be delivered to the state. Similarly, losses are covered by the state. The overall depreciation rate has to be 2% (source: discussion).	☒	☐	☐
1972 - 1985: Introduction of a new accounting strategy. The goal of overall depreciation is 4%, but can vary between minimum 2% and maximum 6% (model assumption). Initially, depreciation is calculated with 2%, but if a profit is resulting, the depreciation is increased up to a rate of 6% or until the break-even point is reached. This could be done since the utility was not expected to make profit, but did not have a reserve account (source: discussion).	☒	☐	☐
1986 - 2004: Introduction of new accounting strategy. Depreciation has to be approximately 4% of the total initial net value of infrastructure. If an individual building is depreciated to zero, then the required 4% depreciation is allocated to another building.	☒	☐	☐
After 2005: Introduction of modified accounting strategy (proposed): goal of depreciation is still 4% per building. But if a building is depreciated to zero, then there is no additional depreciation to be allocated to another building (source: discussion). Note: strategy change will be effective 2002 already.	☐	☒	☐

Table B.33: Task 3: Define financial pressure (situation).

Description in brief	Agreed? yes partly no
The financial pressure is low up to 1990, high as of 1991 up to 1997, then low again after 1997 (source: observation, assumption).	☐ ☒ ☐

Table B.34: Task 4: Define interest and inflation rates.

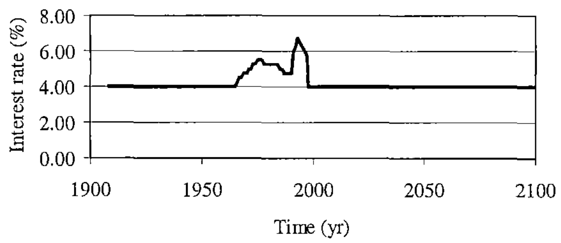
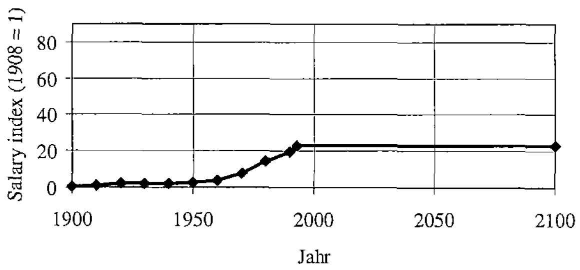
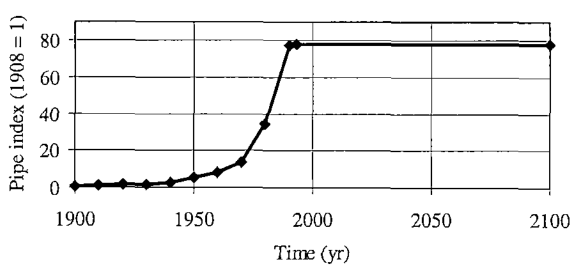
Description in brief	Agreed? yes partly no
Interest rate (source: observation): 	☒ ☐ ☐
Inflation of salaries (source: observation): 	☒ ☐ ☐
Inflation of pipes (source: observation): 	☒ ☐ ☐
Inflation of waterworks, reservoirs and other investments (source: observation):	☒ ☐ ☐

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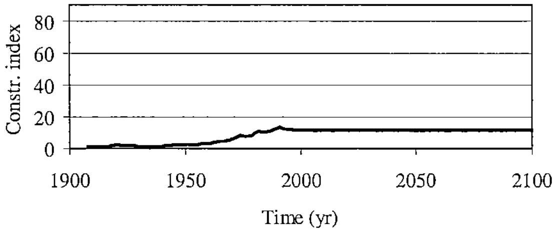
Table B.34: *continued*

Description in brief	Agreed? yes partly no
	

B.6 Characterization of infrastructure

B.6.1 Waterworks

Note that the word "waterworks" is used to describe waterworks (treatment), but pumping stations to transport the water are also included.

Table B.35: Task 1: Get older.

Description in brief	Agreed? yes partly no
If 12 months are past, then waterworks become one year older. For modeling reasons, the update of the age is in november (source: model assumption).	☒ ☐ ☐

Table B.36: Initial settings at beginning of 1908.

Description in brief	Agreed? yes partly no
Two waterworks are assumed. For each waterworks, the initial conditions for age, capacity, initial gross value, initial net value, and book value are assumed according to the documentation (source: Documentation of utility, 1993). Net investments are calculated considering subsidies of 20%. The book value is calculated using a linear depreciation with a rate of 2%.	☒ ☐ ☐

Table B.37: Pro memoria.

Description in brief	Agreed? yes partly no
Parameters in the model: • Mean life-expectancy: 50 years • Standard deviation to life-expectancy: 0 years • Depreciation rate "Basic" (before 1985): 2% • Depreciation rate "SVGW" (as of 1986): 4%	☒ ☐ ☐

continued on next page

Table B.37: *continued*

Description in brief	Agreed? yes partly no
Procedure when building new waterworks: • Decision to design new capacity by utility chief engineer. • Decision for needed amount of capacity by utility chief engineer. • Approval to build new waterworks by utility director, city councillor and parliament (if needed). • During the discussions with the constructing engineering firm, the capacity may be increased. • Cost may be discounted by constructing engineering firm. • The total costs are split linearly during the construction period. • If the age of a waterworks to be renewed (adapted) is smaller than 25 years, then the age does not get reset to zero when building the new plant (assuming that the existing infrastructure is still in good condition and does not need renewal). • If capacity needs to be reduced, either the whole or half of the waterworks' capacity gets shut down, assuming two independent lanes of production. • Depreciation starts at the beginning of the construction period (although the plant is still under construction and not yet in use).	☒ ☐ ☐

B.6.2 Reservoirs

Table B.38: Task 1: Get older.

Description in brief	Agreed? yes partly no
If 12 months are past, then reservoirs become one year older. For technical reasons, the update of the age is in november (source: model assumption).	☒ ☐ ☐

Table B.39: Initial settings at beginning of 1908.

Description in brief	Agreed? yes partly no
The number of existing reservoirs as well as their initial age and capacity, respectively, are estimated based on the given data (source: Documentation of utility, 1993). The initial settings of the reservoirs include age, volume, initial gross value, initial net value, and book value. Net investments are calculated considering subsidies of 20%. The book value is calculated using a linear depreciation procedure with a rate of 2%.	☒ ☐ ☐

Table B.40: Pro memoria.

Description in brief	Agreed? yes partly no
Parameters: • Theoretical life-expectancy: 50 years • Standard deviation to life-expectancy: 0 years • Depreciation rate "Basic" (before 1985): 2% • Depreciation rate "SVGW" (as of 1986): 4%	☒ ☐ ☐

continued on next page

Table B.40: *continued*

Description in brief	Agreed? yes partly no
Procedure when building new reservoirs: • Decision to design new reservoirs by utility chief engineer. • Decision for needed volume by utility chief engineer. Is based on average consumption. Since several reservoirs are present, no extrapolation of consumption is made. Not needed as reservoirs also depend on pressure zones. There are enough reservoirs in order to be flexible. • Approval to build new reservoir by utility director, town councillor and parliament (if needed). • During the discussions with the constructing engineering firm, the volume may be altered (increased). • Cost may be discounted by constructing engineering firm. • The total costs are split linearly during the construction period. • Existing reservoirs are not adapted, but new ones are built if new volume is required. • If volumes need to be reduced, the whole reservoir gets shut down. • Depreciation of the reservoirs starts at the beginning of the construction period, although the reservoir is still under construction and not yet in use (this is in conflict with reality, but is done this way in the model in order to be consistent with waterworks).	☒ ☐ ☐

B.6.3 Pipes

Table B.41: Task 1: Get older.

Description in brief	Agreed? yes partly no
If 12 months are past, then pipes become one year older. For technical reasons, the update of the age is in november (source: model assumption).	☒ ☐ ☐

Table B.42: Initial settings at beginning of 1908.

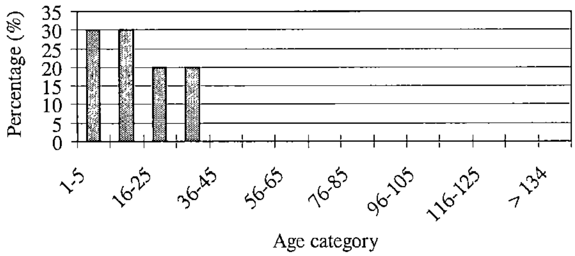
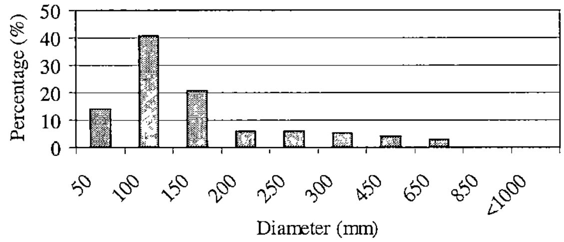
Description in brief	Agreed? yes partly no
Age distribution. According to the given data in the annual utility reports, the age distribution is as follows:  	☒ ☐ ☐
Diameter distribution: According to the given data in the annual utility reports, the diameter distribution is as follows:  	☒ ☐ ☐
Life-span distribution: The theoretical (mean) life-span of the pipe mains at the beginning of the century was 80 years (cast iron). A gaussian random distribution is superimposed with a standard deviation of 10 years. The following distribution of the expected life-span emerges (source: Trujillo Alvarez, 1995, observations, discussion):	☒ ☐ ☐

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Table B.42: *continued*

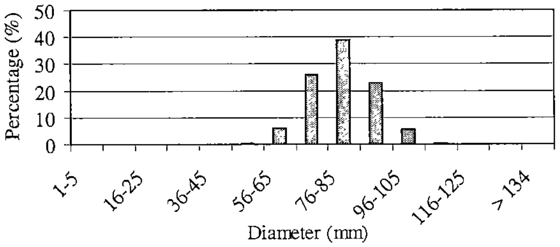
Description in brief	Agreed? yes partly no
	
The value of pipes in the model ranges up to 50% of the value of the total modeled infrastructure at the beginning of the modeled period. Gross investment costs are calculated based on the estimated investment cost curve (B.2), taking inflation into account. Net investments are calculated considering subsidies of 20%. The book value is calculated using a linear depreciation with a rate of 2%.	☒ ☐ ☐

Table B.43: Pro memoria.

Description in brief	Agreed? yes partly no
Parameters: • Up to 1964: Material = cast iron, 80 years • 1965 - 1991: Material = ductile iron, 40 years • As of 1992: Material = ductile iron with exterior protection, 100 years • Standard deviation to life-expectancy: 10 years • Depreciation rate "Base" (before 1985): 2% • Depreciation rate "SVGW" (after 1986): 4%	☒ ☐ ☐

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Table B.43: *continued*

Description in brief	Agreed? yes partly no
Procedure when building a new pipe: • Decision to design a new pipe by utility chief engineer as a result of population growth or of the ageing of an existing pipe. • If a new pipe has to be built, the diameter is determined in the following manner: It is assumed that the diameter distribution of 1908 represents the structure of the city well. If the city grows, it is assumed that it grows harmoniously, meaning that the diameter distribution remains the same. But, as the city will be populated more densly and people are using more water per capita, the diameter distribution must be shifted to the right, towards larger diameters. As a measure of how much the pipe diameter needs to be enlarged, the ratio of capacity per capita is taken between the actual and the initial year (1908). The two steps to choose the diameter are: – Choose diameter. The actual diameter distribution is compared with the initial (1908) one. A diameter is chosen so that the two distributions stay similar. – Transform diameter. The chosen diameter is transformed towards a larger one, taking the development of capacity per capita into account. $$d_{needed} = d_{givenFromDistribuition} * \left(\frac{capacityPerCapitaToday}{capacityPerCapita1908}\right)^{2/5}$$ The formula assumes that the flow through the individual pipes is proportional to the overall capacity at any time, no matter where the pipe is within the network. As pipes are built taking a planning horizon into account, it is assumed that the ratio of the capacity at the planning horizon to the existing capacity is the same at all times. The exact development of the above formula can be seen in Gujer (1999), p.158. The formula assumes round pipe diameters and equal pressure losses. The formula is derived by the combination of the Bernoulli equation and the calculation of head loss by Darcy-Weissbach. • If an existing pipe needs to be renewed as a result of its age being greater than its life-expectancy, the above transformation factor for the new diameter is calculated as well. However, an existing diameter would not be decreased, since the pipe needs to maintain compatibility with the neighboring pipes. • Construction period of pipes is neglected in the model. Since pipes are constantly being built, this assumption will not influence the model output significantly. • The cost for pipe constructions is paid with no delay. • Pipes are depreciated based on their initial net value.	☒ ☐ ☐

Appendix C

Model Design

The component that organizes the agents is a "swarm". A swarm is a collection of agents, but also an agent itself (Fig. C.1). All swarms are also agents, but not all agents are swarms. For example, stakeholders groups such as "consumers" are implemented as a swarm. This swarm contains agents such as "people", "industry" and "partners". These agents in turn are at the same time swarms. The swarm "people" for example contains agents such as the individual houses, firms or partners. This modularity and composability of swarms and agents allows for a flexible modeling system.

The class diagram of the relation between swarms and agents is given in Fig C.2. Figure C.3 shows the relation between the agents and the objects in order to view them, the viewers. The class diagram of the developed model is shown in Fig. C.4. An example of interaction between swarms and agents is given in Fig. C.5 (interaction diagram).

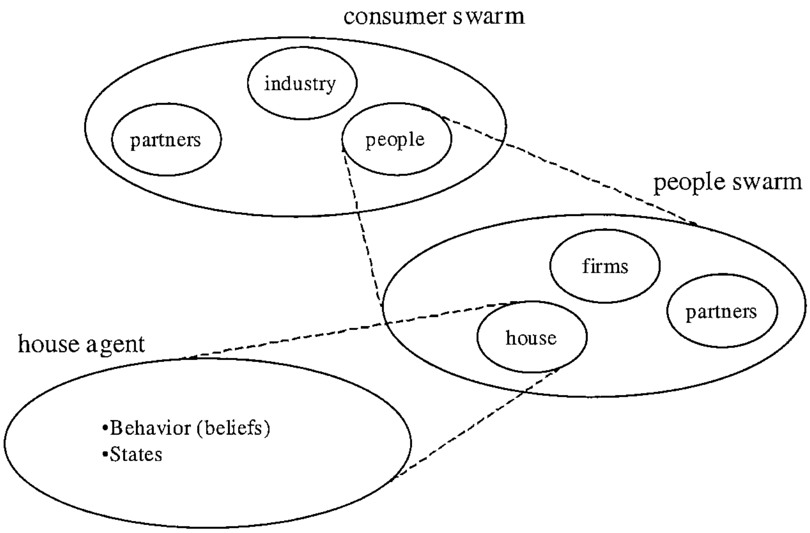

Figure C.1: *Nested swarms and agents. A swarm is a collection of agents, but also an agent itself.*

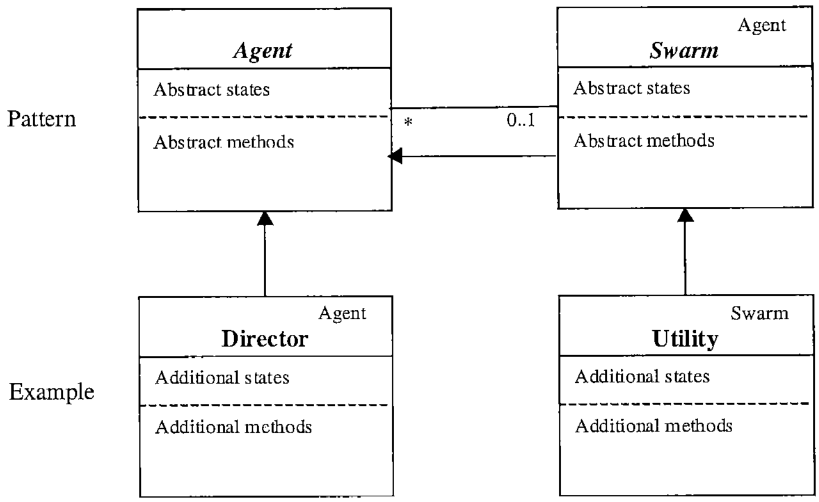

Figure C.2: *Composite pattern (relation between agent and swarm). Legend see C.3.*

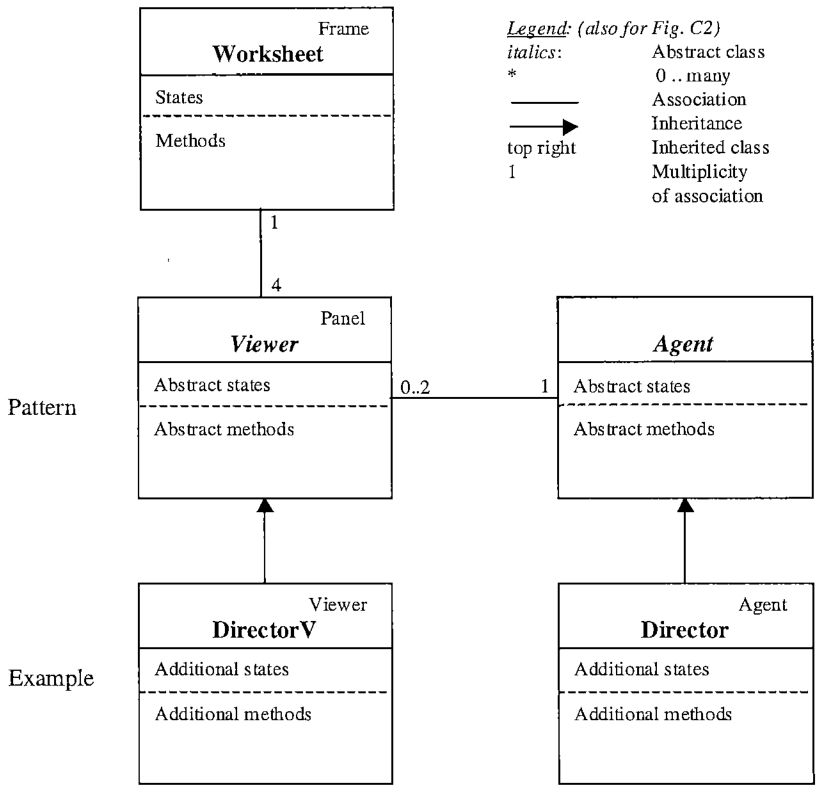

Figure C.3: *Model-viewer pattern (relation beween viewers and agents).*

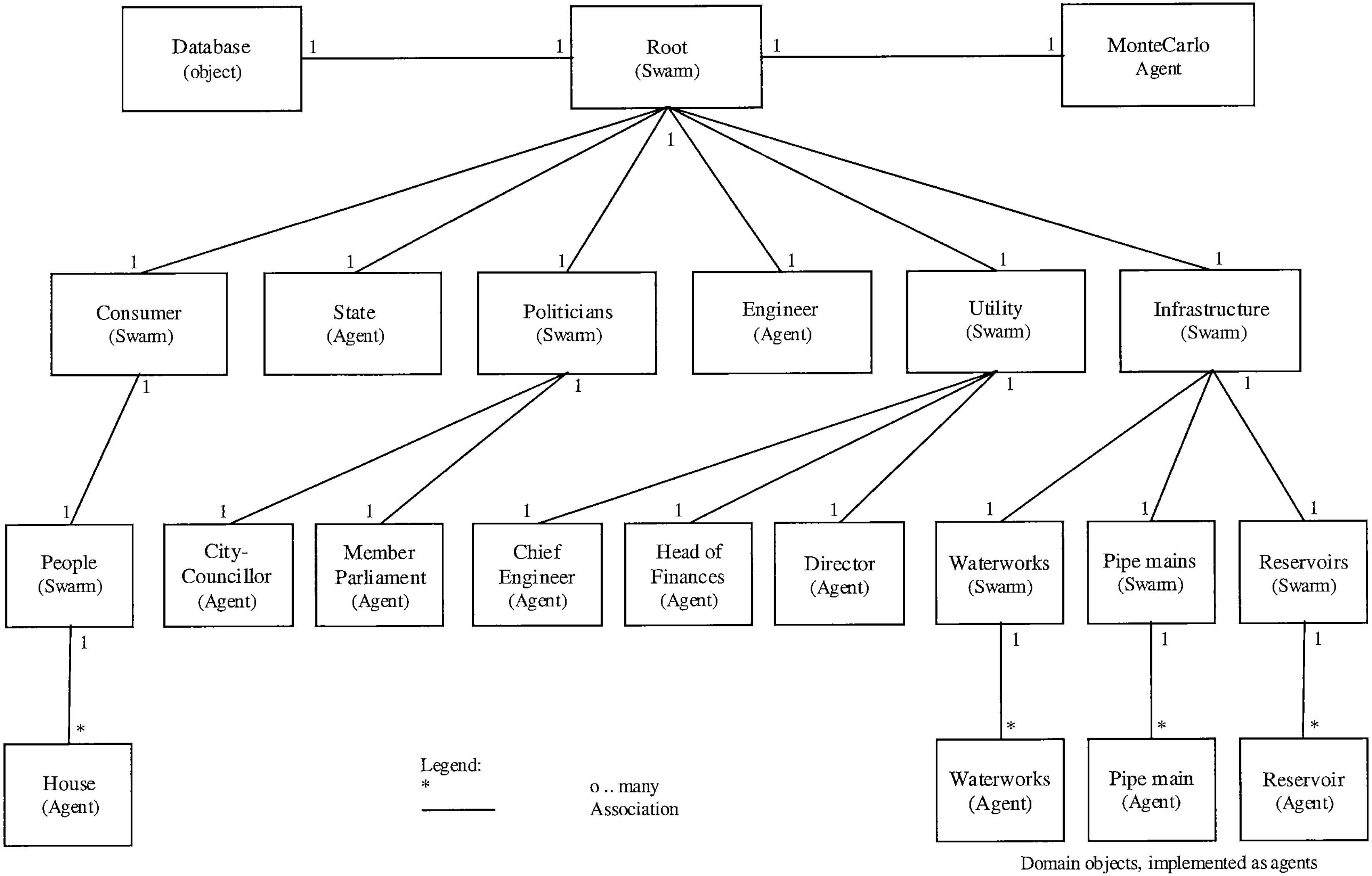

Figure C.4: Class diagram of model.

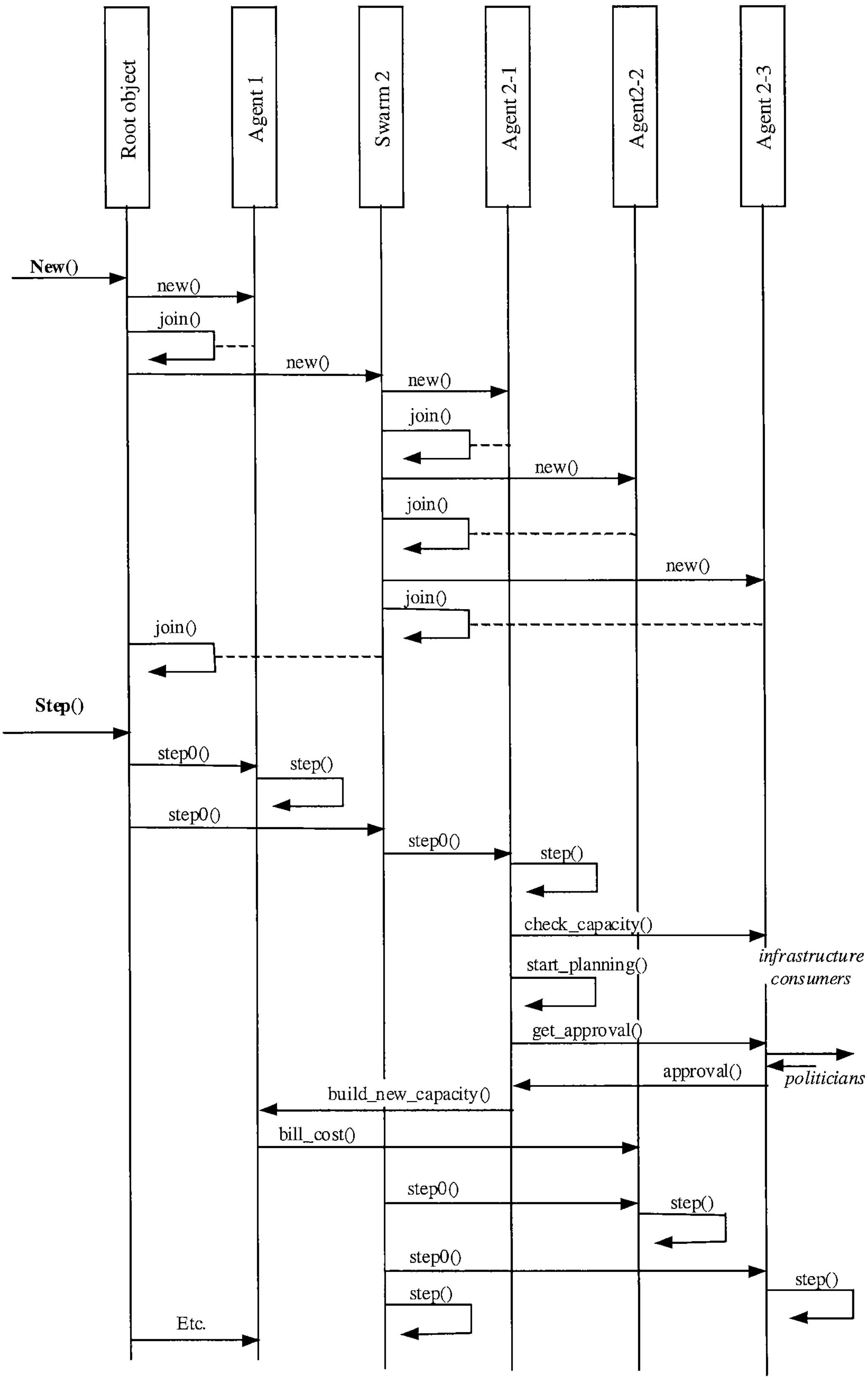

Figure C.5: Interaction diagram of model.

Appendix D

Parameter List

Table D.1: List of parameters for model validation and scenarios. Validation = default values during vaidation period (1908 – 1996), Scenario = default values during scenario simulations (1997 – 2100). D = evaluated from observed data, P = evaluated in participatory process, A = assumption. MC = variable in MonteCarlo mode.

Parameters	Unit	Validation	Source	Scenario	Range	MC
Boundary conditions						
Consumers						
Population development	%/yr	given	D	0.0	-0.5 – 0.5	-
Specific consumption development	%/yr	given	D	0.0	-0.5 – 0.5	-
Connection Fees	%/yr	given	D	4.0	2.0 – 6.0	-
Inhabitants/house	#	1000	A	1000	-	-
Water-meter/capita	m^3/h	0.8	D	0.8	0.6 – 1.0	√
Consumed by town (people, industry)	%	65	D	65	-	-
Paid by town (people, industry)	%	75	D	75	-	-
State						
Accounting strategy 1 before	yr	1972	D	-	-	-
Accounting strategy 2 before	yr	1986	D	-	-	-
Accounting strategy 3 before	yr	-	P,A	2005	-	-
Financial pressure high as of	yr	1990	D	1990	1980 – 2000	√
Financial pressure low after	yr	-	D	1997	1997 – 2100	-
Interest rate (debt)	%	given	D	4.0	2.0 – 6.0	-
Subsidies	%	given	D	5.0	1.0 9.0	-
Inflation	%	given	D	0.0	0.0 – 3.0	-
Behavior						
Consumers						
Price elacticity	-	none	D,A	-0.2	-1.0 – 0.0	-
Peak reduction potential	%	none	A	0	0 – 60	-

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Table D.1: *continued.* Validation = default values during vaidation period (1908 – 1996), Scenario = default values during scenario simulations (1997 – 2100). D = evaluated from observed data, P = evaluated in participatory process, A = assumption. MC = variable in MonteCarlo mode.

Parameters	Unit	Validation	Source	Scenarios	Range	MC
f-min (min ratio max/ave)	-	given	D	1.2	1.1 – 1.3	-
f-max (max ratio max/ave)	-	given	D	1.7	1.4 – 2.0	-
Memory price raise	yr	3	A	3	1 - 5	√
Utility director						
Strategy (rule set)	-	past	P	past	or present	-
Minimum cost split fees/turnover	%	40	D,P	40	20 – 40	√
Maximum cost split fees/turnover	%	41	D,P	41	41 – 60	√
New price when	%	15	P	15	10 – 20	√
Influence periode (present)	yr	-	A	5	-	-
Utility chief engineer						
Strategy (rule set)	-	past	P	past	or present	-
Wanted capacity reserve	%	20	P	20	5 – 35	√
Minimal capacity reserve	%	-	P	5	0 – 10	√
Planning horizon	yr	20	P	20	5 – 35	√
Years for regression past (not in GUI)	yr	all	P	all	-	-
Years for regression present	yr	-	P	10	5 – 15	√
Urgent renewal if remaining age	yr	-	P	-20	-30 – -10	√
Max renewal rate	%	1.5	D	1.5	0.5 – 3.0	√
Annual maintenance + upgrade	%	3	D,A	3	2 – 4	√
Volume wanted	%	80	P,A	80	70 – 90	√
Volume needed	%	-	A	60	50 – 70	√
Utility head of finances						
Strategy (rule set)	-	past	P	past	-	-
Increase income by	%	15	P	15	10 – 20	√
Depreciation rate basic	%	2.0	D	2.0	-	-
Depreciation rate SVGW	%	4.0	D	4.0	-	-
Depreciation after 2005 (not in GUI)	%	-	P	4.0	-	-
Constructing engineer						
Strategy (rule set)	-	past	P	past	or present	-
Duration renovation	yr	0	P	0	0 – 1	√
Duration short	yr	2	P	2	1 – 3	√
Duration medium	yr	3	P	3	2 – 4	√

continued on next page

Table D.1: *continued.* Validation = default values during vaidation period (1908 – 1996), Scenario = default values during scenario simulations (1997 – 2100). D = evaluated from observed data, P = evaluated in participatory process, A = assumption. MC = variable in MonteCarlo mode.

Parameters	Unit	Validation	Source	Scenarios	Range	MC
Duration long	yr	4	P	4	3 – 5	√
Duration pipe mains (not in GUI)	yr	0	A	0	-	-
Past: volume increase	%	10	P	10	5 – 15	√
Cost increase/decrease	%	20	P,A	20	10 – 30	√
Cost factor renovation/shutdown	-	0.5	A	0.5	0.2 – 1.0	-
City councillor						
Safe finances factor	%	0	P/A	0	-	-
Members of parliament						
Opinion factor	%	50	A	50	30 – 70	-
Infrastructure						
Mean life span waterworks	yr	50	P	50	30 – 70	√
Standard deviation life span	yr	0	A	0	-	-
Max number of waterworks (not in GUI)	#	3	A	3	-	-
Min number of waterworks/res. (not in GUI)	#	2	P	2	-	-
Mean life span reservoirs	yr	50	P	50	30 – 70	√
Standard deviation life span	yr	0	A	0	-	-
Pipes per inhabitant (not in GUI)	m	given	D	2.8	-	-
Pipes type 1 built until	yr	1964	P	-	-	-
Life span pipes type 1	yr	80	P	-	70 – 90	√
Pipes type 2 built until	yr	1991	P	-	-	-
Life span pipes type 2	yr	40	P	-	30 – 50	√
Pipes type 3 built after	yr	1992	P	1992	-	-
Life span pipes type 3	yr	100	P,A	100	40 – 110	√
Standard deviation life span	yr	10	D	10	-	-
Length per pipe	m	1000	A	1000	-	-

Appendix E

Curriculum Vitae

Donald E. Tillman

Date of birth	May 4, 1966
Citizen of	Meilen (CH)
Nationality	Swiss and British
Contact	tillman@alum.mit.edu

1981 – 1985	Gymnasium for Mathematics and Sciencies, Zürich, Matura Type C
1986	Military service
1986 – 1991	Dipl. Ing. ETH in rural engineering, Swiss Federal Institute of Technology, Zürich
1991	Advanced language course in spanish, Ecuador. Military service in swiss-french unit
1992 – 1995	Holinger Ltd, Baden, Switzerland (environmental consultants). Assistant project manager and expert on several projects: Project management of environmental impact statements, quality assurance, coordination and mediation between authorities, construction engineers, environmental engineering firms and public. Bioengineering revival studies and hydraulic calculations. Assessments of impact on soil. Redesign of municipal sewer systems, capacity and economic analysis of sewers.
1993 – 2001	Tennis instructor, teacher and consultant "youth and sport"
1995 – 1996	M.Eng. in civil and environmental engineering, Massachusetts Institute of Technology, Cambridge, USA
1996 – 2001	Dissertation at EAWAG, Dübendorf, in the group of Prof. Dr. W. Gujer, department of engineering sciences
1996 – 2001	Teaching and research assistance, ETH Zürich