Check for updates

Simulating development strategies for water supply systems

D. E. Tillman, T. A. Larsen, C. Pahl-Wostl and W. Gujer

ABSTRACT

The objective of this paper is to point out existing risks of current design and management strategies in water supply systems and to identify possible ways of designing and operating schemes which minimize these risks. This paper is motivated by the observation that existing design principles and engineering rules (best practice) seem to cope insufficiently or even conflict with current trends of declining water demand. In order to evaluate this situation, an agent-based model comprising the current rules of best practice was developed in a participatory process. Once the model was validated with data sets from a real utility, multiple-scenario testing was used to explore different design strategies, thus allowing ideas for developing alternative management and design schemes to be generated. The simulations show that the traditional risk of insufficient supply security must be supplemented by considering the opposite risk of excessive security (over-capacity). The introduction of demand-side measures may help to calibrate existing best practice with the trends of the current operating environment. Ideas are brought forward on how to shape incentive systems for stakeholders in order to facilitate such a shift.

Key words | agent-based modelling, demand-side management, management strategies, rule-based expert system, social science simulation, water supply systems

D. E. Tillman (corresponding author)
SAM Sustainable Asset Management,
Seefeldstrasse 215,
8008 Zürich,
Switzerland
E-mail: *tillman@alum.mit.edu*

T. A. Larsen
Swiss Federal Institute for Environmental Science and Technology (EAWAG),
8600 Dübendorf,
Switzerland

C. Pahl-Wostl
Institute for Environmental Systems Science,
University of Osnabrück,
49069 Osnabrück,
Germany

W. Gujer
Swiss Federal Institute of Technology (ETH),
8093 Zurich,
Switzerland

INTRODUCTION

Many cities grew enormously during the preceding century. Waterworks (i.e. a combined water purification plant and pumping station) succeeded in consistently providing water in the amounts and quality required by consumers even during periods of rapid growth. In response to the conditions prevailing during the last century, the concepts and design rules created by water engineers evolved and generally provided excellent solutions to standard problems. They have now become established as standards and are known as 'best practice' (state of the art), also influencing further regulatory efforts. Examples of best practice are: supply-oriented management (not controlling demand but supplying the water that is demanded), worst-case planning, the concept of including safety factors to cope with uncertainty (versus working with probability distributions) and accepting the accumulation of safety factors through several design steps, extrapolation of past patterns of development (sometimes considering long historical records), income compensation of consultants (designing engineers) according to constructional dimensions, design concepts based on centralized systems, etc.

These concepts of best practice, however, do not seem to always be well adapted to coping with existing challenges. We can observe that at many locations supply capacity became expanded in recent years although the demand trend was decreasing. This lead to an increase of capacity reserves, which eventually became 'over-capacity'. The consequences are that utilities are confronted with standing water in pipe mains, and that political stakeholders tend to question the overall efficiency of the technical system. Such problems become

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

even more evident when assuming a further decrease in water consumption by, say, 50%. While industrial companies are working at high speed to develop installations leading to such a decrease (e.g. water-efficient dishwashers, water-less urinals, low-flush toilets, etc.), current water supply systems cannot adapt to such a development fast enough with existing best-practice strategies.

When comparing the operating environment of today with that for times when the existing best practice was developed, two major changes are salient and may explain why there is a potential mismatch between (past) best practice and (existing) engineering problems. The first change relates to the type of design tasks. The past century was generally dominated by the initial construction of the infrastructure and its further enlargement as the number of consumers served, as well as the specific water consumption, grew. Today, in contrast, the design tasks are related to the renewal of system elements: the upgrading of water works, replacement of water mains or even downsizing the system. These new tasks are most likely to require different planning and design rules than those developed in the past. As an example, let us consider the case where a waterwork needs to be renovated. As supply systems were constructed in a centralized manner in the past (best practice, e.g. only a very few but large waterworks produced the water for the whole network), the temporary shutdown of such a waterwork due to renovation needs would potentially lead to large water deficits in the supply system. From a renovation point of view, it would be much better if there would be many decentralized smaller waterworks, so that the renovation of such a work would not harm the rest of the supply network too much.

A second change relates to the demand trend as already indicated above. In the past, water utilities were confronted with generally increasing water demand. This situation changed about 2–3 decades ago. Specific consumption now generally decreases, mainly due to the more efficient water use in industry (recycling) and the introduction of more efficient sanitary installations. Hence, we may have a conflict with the method of including safety factors in several design steps. In times of rising water demand this method provided the required safety margins to cope with increasing demand. However, in view of the declining water demand today, the use of accumulating safety factors may lead to oversized infrastructure.

Existing engineering concepts and design rules must be adjusted to respond to these recent developments. Of course best practice is continuously adapted in daily work, but it seems that an incremental change may not be substantial enough and sub-optimal in view of least cost and overall benefits to society. However, we may also need to ask for reasons why existing design strategies were not changed rapidly enough, leading to these deficits as observed. On the one hand, there are technical constraints: compatibility problems with the mains, supply security aspects in the case of system failures and regulations requiring a 0% system failure rate (demanding even more infrastructure). On the other hand, the incentives given to various stakeholders involved in the planning process (engineers, politicians, city planners, consumers, etc.) are such that the stakeholders do not have any interest to change best practice significantly. We assume that these incentives and interests play a major role.

Incentives and interests

According to the standard economic theory of rational choice and utility maximization, the interests of stakeholders are directed predominantly to private benefits. Some examples are ways of maximizing profit or enhancing status. Together with the requirement to do a good job, interests to maximize private benefits may also have a strong impact on the development of best practice. For example, private companies may suggest not only a functioning engineering solution, but also one where they can earn additional income.

The interests of stakeholders must be seen in the light of the incentives given to them by regulations. Incentives influence the outcome of a planning process by setting the boundary conditions within which the stakeholders can optimize their response on the basis of their interests. Some incentives currently given to stakeholders are in conflict with the goal of having a water supply infrastructure which is reliable as well as lean, cost-effective and flexible. For example, the large subsidies paid by state agencies in the late 1980s tempted planners, engineers and

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

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, as eventually happened in the early 1990s. Infrastructure was sometimes built as fast as possible without any detailed investigation as to whether it was really necessary or whether better alternatives existed. Hence, at that time, developments were strongly influenced by financial incentives from the state and detailed technical or system-related considerations were given lower priority.

Unfortunately, it is rather difficult to quantify the influence of these interests and to engage in an objective discussion about their effects. Stakeholders hardly ever reveal their real interests explicitly and their assessment of the situation is subjective.

Research questions

The following research questions are addressed in this paper:

- A methodology to elicit knowledge from stakeholders to discover and depict interests and the resulting rules of behavior (best practice).
- A simulation platform to evaluate benefits and risks of existing best practice.
- The discussion of alternative best-practice concepts which optimize or mitigate the risk of existing best practice.

PREVIOUS WORK

The relevance of stakeholder interaction and institutions gains increasing attention in the domain of water resources and water supply systems. Finger & Allouche (2001) as well as Nunes Correia & Krämer (1997) give an overview of relevant stakeholders. Minsch *et al.* (1998) analyze stakeholders with the aim of achieving sustainable development, Grimble & Chan (1995) do the same for developing countries. The importance of stakeholders is also highlighted and discussed in many other domains, such as information systems and management science (e.g. Guy & Marvin 1996). Bakker *et al.* (1999) provide a framework for institutional analysis with respect to managing flood and drought risks, where institutions are understood as the invisible shared beliefs and ‘rules of the game’. This research field is particularly influenced by the work of Ostrom (1986).

Several models have been developed which attempt to describe the processes of reasoning, planning and choice, and generate a mechanistic model of human behavior. 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 (Dahrendorf 1958). It tries to model action essentially based on the rules imposed by society (norms, roles, constraints). The ‘Theory of Planned Behavior (TOPB)’ (Ajzen 1985) also belongs to this group. In the field of water supply systems, some first attempts to model water consumers have been made (Jager *et al.* 1999). Within the research field of distributed artificial intelligence (Langton 1989), many examples have shown that the development of emergent social properties can be explained by the application of relatively simple ‘if–then’ rules to individual agents (Gilbert & Troitzsch 1999).

The existing methodologies and models are characterized in that they either focus on one specific aspect of behavior and model it with great accuracy, or that the models cover large systems in an abstract mode. No model has been developed so far which, on the one hand, addresses the problems of whole water supply systems in a manner which is accurate enough to discuss the model and its implications with stakeholders and, on the other hand, a model which can be validated with real data, but which is also simple enough to manage the complexity of the model. The following methodology has been laid out in Tillman *et al.* (2001). The current paper emphasizes the findings from some simulations.

METHODOLOGY

The methodology developed comprises the following steps:

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

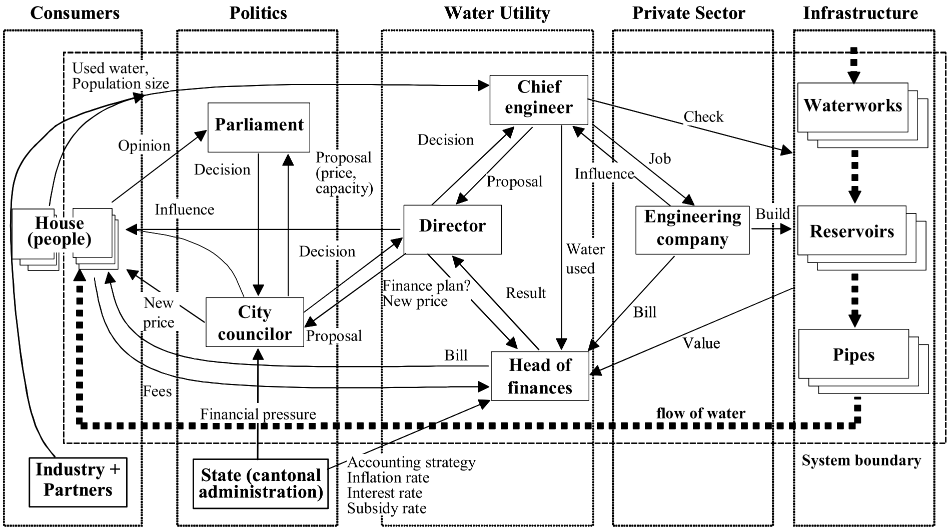

Figure 1 | Model developed and interactions linking stakeholders and domain objects. The dashed arrows visualize the water flow.

- Typical rules of behavior of influential stakeholders are proposed by a facilitating knowledge engineer on the basis of the literature, interviews and observation. The rules are then expressed in an 'if (condition)–then (action)' format.
- These rules are discussed, analyzed, changed and supplemented with the aid of domain knowledge obtained from the stakeholders involved in a participatory process. This process results in a rule catalogue which documents the characteristic goals, interests, strategies and rules of behavior.
- An agent-based computer model comprising these rules of behavior is subsequently developed. The validity of the model is checked by modelling the historical development of a real utility and comparing the model output (capacity, investments, water tariff, debt, etc.) with the reality. A sensitivity analysis helps to check the relevance of individual parameters which form part of the rules.
- Multiple-scenario testing is used to explore different management and engineering strategies, thus allowing ideas for developing flexible management and design schemes to be generated and tested. The scenarios are discussed with the stakeholders.

This methodology has the benefits that, on the one hand, it serves to structure the discussion, which results in an improved quantitative understanding of the incentives and constraints of the stakeholders and the decision-making rules which they apply. On the other hand, the resulting model allows specific scenarios of newly generated rules to be tested.

Note: as this paper is intended to serve as an overview, neither a detailed description of the stakeholder rules nor further explanations and figures concerning the sensitivity analysis is given. These aspects can be found in Tillman (2001). At this point it must also be stressed that, as this model aims to describe a complete water supply system, the goal was to capture the overall behavior without going into too many details (e.g. modelling specific negotiation processes among stakeholders). It is also evident that all the restrictions and concerns involved in modelling the behavior of complex social systems apply.

RESULTING MODEL

The stakeholders modelled and the interactions revealed during the process of rule evaluation are shown in Figure 1. The arrows reflect the links between stakeholders and

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

domain objects. The dotted 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 modelled. 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. However, they are neglected in the model for reasons of simplicity. Further links are also present in that all stakeholders shown are consumers at the same time. In principle, therefore, they also see things from a consumer's perspective.

Input parameters, which are triggering the action of the other stakeholders, are population growth and the specific water consumption. The time period which is modelled ranges from 1908 to 1996. The starting point of 1908 was chosen based on historical data present from a real utility to be used for validation. The model was constructed from scratch using an agent-based model structure in Java. The model structure was guided by ideas developed in the modelling tool Quicksilver (Burse 2000).

The model contains 140 rules of stakeholder behavior. They were developed according to the methodology described together with five representative stakeholders: a utility director, a utility financial officer, an engineering consultant, the head of the water association and an executive politician. The process was facilitated by a knowledge engineer. In the case of conflicting statements of stakeholders, a facilitating process resolved the differences. Conflicting interests and behavior however—as recognized during the process—were not eliminated, as this is part of the daily behavior of stakeholders.

As it was the intention to develop an initial set of rules which could be further elaborated in the following studies, the number of stakeholders included in the project was deliberately held to a minimum.

MODEL VALIDATION

Based on the emerging rules of stakeholder behavior, the model is able to replicate the general development of the capacity of a Swiss water utility (Figure 2). The rules are designed to reflect the typical way of action of the past decades. A sensitivity analysis is given in Tillman (2001).

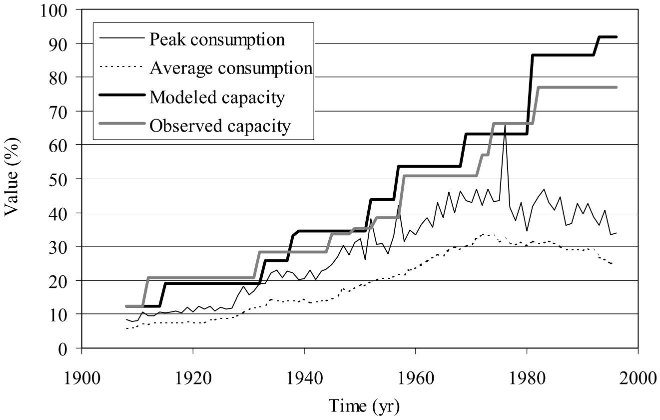

Figure 2 | Model validation comparing the observed capacity of a large Swiss utility with the modelled capacity development based on the model rules. Consumption development is given. The model can replicate the general major steps, although details and timing are not always accurate. Also financial variables were modelled but not discussed in this paper.

These rules, summarized as 'Strategy A (past)', are characterized by a high emphasis 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. The design engineer of the utility believes in a long-term consumption trend and thus includes this in his calculations for designing new capacity (through linear extrapolation). Management concepts aiming to influence consumers and reduce demand peaks are not considered and consumption is assumed to be price-inelastic. Since no strong competition between the rival construction companies is factored in (implying the concept of a 'house engineer'), prices are relatively high: costs are increased by 20% over the 'normal' price. The non-competitive situation also leads to a 10% increase in construction volume, reflecting the interests (profit maximization, which is dependent on the size of the construction project) of the engineers.

Even if these rules of the past seem on first sight simplistic, they capture the essence. While these rules represent the way in which the participating stakeholders behaved in the past, it has to be emphasized that over the

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

last five years the stakeholders have started to shift their behavior so as to adapt to the changing environment.

EXPLORATIVE STRATEGY SIMULATION

Based on the questions described in the introductory section, the model allows simulating alternative design strategies by changing certain rules or parameters of the rules. These alternative strategies can be applied in retrospect or to test them on future consumption scenarios. Two main scenarios shall be explored here. Both serve as examples of the kind of question that can be addressed using the model.

- Scenario 1. Influence of extreme demand peaks. Based on the existing paradigm to avoid influencing the water demand of consumers, it shall be explored what effect the acceptance of demand peaks has on the development of the infrastructure.
- Scenario 2. Reducing over-capacity. Given the increasing spread between capacity and demand (see Figure 1), alternative rules of behavior shall be tested that can better cope with decreasing demand trends and avoid large capacity build-ups.

Scenario 1: influence of peaks

The influence of extreme demand peaks on capacity development according to the model rules was analyzed. The consumption peak of 1976 (as a result of a dry weather period in June of that year) is well known in the Swiss water supply engineering community. It is often used as an argument for the need to maintain sufficient capacity reserves at all times. Accordingly, this peak provided the justification for large investments over the past 30 years.

Figure 3 shows the difference in capacity development as a result of the occurrence of this one demand peak. The final capacity value differs in a comparison of the two simulations: the peak of 1976 accounts for a capacity difference of about 15%. It may even account for a higher percentage, because in its absence it may have become apparent earlier that the general consumption trend was flattening out and that a change of engineering rules may be appropriate.

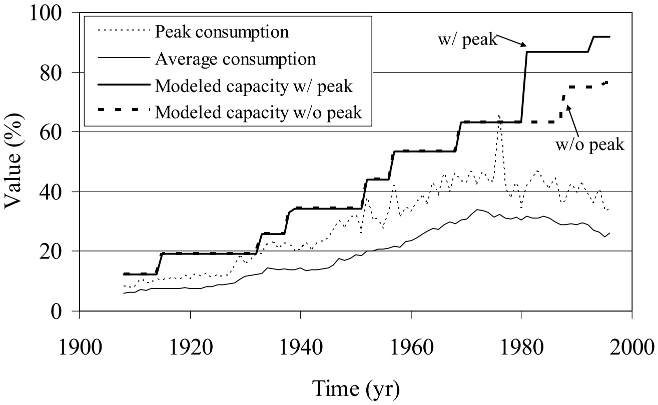

Figure 3 | Influence of peaks. Modelled capacity development using strategy A, influenced by the large peak in 1976. The occurrence of a single peak (over less than 15 days) significantly influenced further capacity development (modelled capacity with peak). For the modelled capacity development without the peak of 1976, the peak was assumed not to happen. As a result, significantly less capacity would have been built (modelled: capacity without peak; dashed: capacity development after 1976).

If lean capacity development is targeted, it seems important to control the extreme demand peaks. They are particularly relevant as their occurrence greatly influences the further development of capacity. They are also suspected of generating further peaks because the expanded capacity allows these to occur. Regulations should be considered to be adapted to allow flexible peak control, but not only in the case of scarce capacity but also in the case when abundant capacity is present.

The stakeholders involved found it most interesting to experience the relevance of peaks and to have it displayed graphically. However, they argue that at the time there was no need to influence the peak (sufficient capacity was available). The peak was also a welcome means of demonstrating the benefit of the existing capacity reserve. Although they agree that it is necessary to influence peaks at times of scarce capacity, they simultaneously argue that it is a political task to ‘eliminate’ peaks. So far, the regulations have not taken this into account.

Scenario 2: alternative strategy to avoid risk of capacity build-up

Existing strategies (Strategy A, past) have difficulties in coping with this situation of decreasing demand

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

Table 1 | Summary of the characteristics of the two different strategies of behavior which were tested in the simulations. Strategy A represents the one with which the stakeholders acted over the past decades. Strategy B is an alternative strategy, which is discussed and compared to strategy A

Stakeholder	Parameters involved	Strategy A (past)	Strategy B (alternative)
Utility chief engineer	Capacity reserves required	Large (20%)	Minimal (5%)
Utility chief engineer	Number of past years considered when extrapolating for planning of future capacity needs	Many (since 1908)	Few (last 10 years)
Utility director	Influence on consumers in order to avoid demand peaks	No. Demand-side management is not targeted for financial and political reasons	Yes. Demand-side management is part of the strategy to match consumption with existing capacity
Constructing engineer	Additional capacity increase for more security	Yes (10%)	No ue to increased competition
Consumers	Price-elastic water consumption	No. Prices are not known and consumption not transparent	Yes. People are influenced and awareness rises. (-0.2)
Consumers	Reduction of peak demand if asked to do so (by the utility, in the case of water shortage)	No. Utility will not ask for water-saving measures	Yes (30%)

(Figure 2). Table 1 summarizes an alternative Strategy B, where—based on strategy A—certain rules and parameters were changed. The characteristics of strategy B are that the capacity reserve requirements are lower but include consistent peak-demand management. It is thus pro-active and attempts to guide the development of consumption peaks consistently whenever existing capacity reserves become small. Since this strategy is communicated effectively to consumers and forms an explicit part of the overall operating procedure, it is assumed that consumers react to such incentives from the utility. This response is expected to result in a 30% decrease of the peak/average ratio if the utility executes its peak management program. Moreover, as the strategy of the utility aims to inform consumers effectively about their personal water use and the associated water costs, it must also be assumed that the consumers will respond 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.

It is, of course, a matter of speculation whether consumption can be influenced in the way assumed in strategy B. More actual field research is needed to show the degree of possible influence. However, indications suggest that consumers may be influenced at least over a couple of days. In certain Swiss cities, calls to reduce water usage as a result of accidents or extreme climatic conditions led to a drop in consumption which exceeded expectations. In order to test strategy B on future developments, a worst case is assumed from the utility's perspective: consumption initially continues to decrease, but suddenly—just after a capacity reduction step—increases again. This possible demand development is often the reason why utilities refrain from reducing existing capacity reserves. So the question is whether a capacity reduction can be accepted in spite of the danger of trend changes.

Strategy B is applied after 1997 (Figure 4). The change in consumption trend is assumed to occur in the year

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

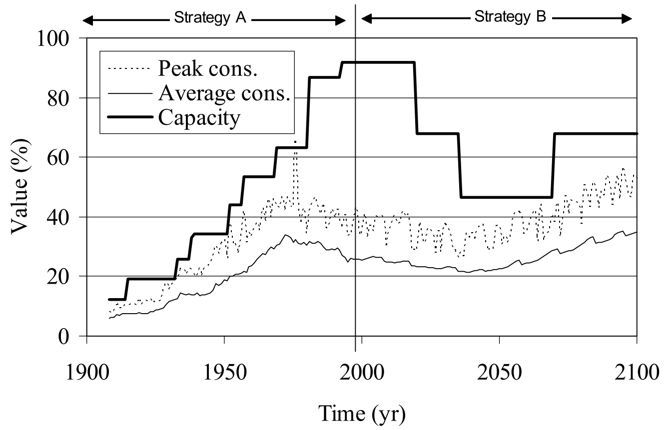

Figure 4 | Performance of strategy B. A change in demand trend is assumed in the year 2040. Average consumption is price-elastic. Peak demand management is applied in times of scarce capacity. A peak was assumed in the year 2065, which could be reduced due to peak demand management and hence a capacity shortage eliminated.

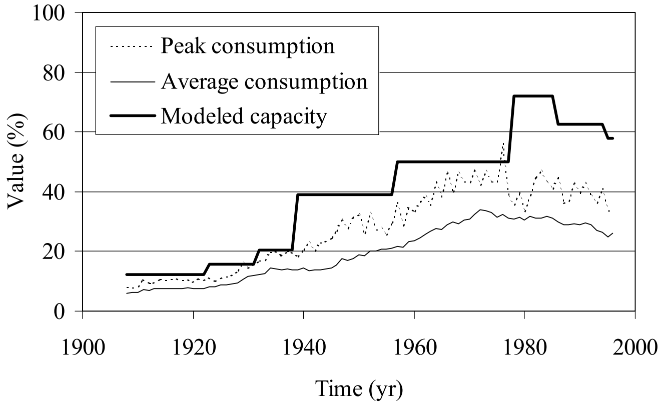

Figure 5 | Performance of strategy B in retrospect. In times of scarce capacity, demand peaks are influenced and become smaller. This strategy would have also provided the required capacity at all times (a minor exception is 1976, see text), similar to strategy A (Figure 2).

2040. The sharp turning point was deliberately chosen to occur at that time, since capacity is reduced immediately before it (worst case). In addition, an extreme peak is assumed at 2065. However, this peak is not visible in Figure 4 as it was reduced due to the peak demand management efforts of the utility (the peak was given as a simulation input parameter, but the rules of the stakeholders applied resulted in a flattening of the peak). After 1997, capacity is subsequently reduced in view of the large reserves available up to the year 2040 (the time when reduction takes place is dependent on the age of the infrastructure). Consistent information and response of consumers is assumed, resulting in obvious sensitivity to prices and peaks. As a result, the peak value at 2065 can be successfully influenced and reduced. Because it is assumed that consumers can be influenced over short periods (a couple of years, see Table 1), more time is available for adapting capacity. The planning procedure for new capacity starts at about 2062 (according to the strategy rules), but capacity is not built before 2066 due to the time lag in construction.

The scenario shows that capacity can be reduced without losing security of supply. Obviously, many details must still be examined to reach firm conclusions, especially as regards the local situation and the properties of the pipe infrastructure. And yet the scenario shows that it may be worthwhile to increasingly consider such management rules. As utilities will most probably have to reduce capacity at some time, it is interesting to realize that a reduction of capacity reserves *in combination with* the introduction of demand-side measures may not diminish supply security even with the emergence of worst-case consumption.

During the discussions of this scenario, the utility managers confirmed the need to reduce existing capacity if the decreasing consumption trend continued. However, their concerns are still of a technical nature and they anticipated technical problems and listed the reasons why a reduction suggested by the scenario may not be possible (location of waterworks, effects on the network, effects of the failure of waterworks, etc.). Hence, it became apparent that a reduction—although required—tends to be delayed as long as possible, which may be a critical strategy in the long run. The effects of reductions are still not studied enough to become familiar with them.

Scenario 3: strategy B in retrospect

Considering the development of consumption observed in the past (1908–1996), strategy A is not the only way to provide supply security. Also strategy B would have been mostly successful (Figure 5). The only minor bottleneck

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

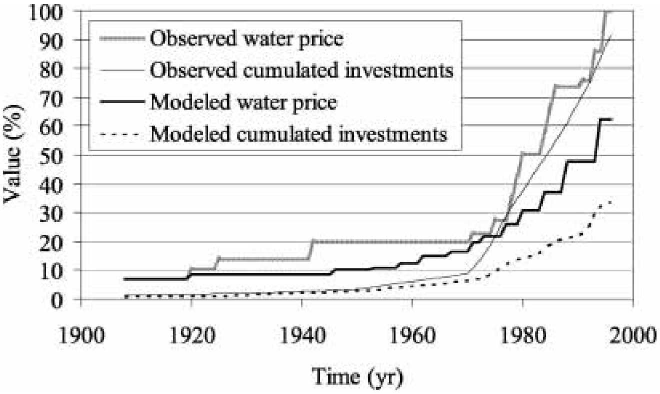

Figure 6 | Effects of strategy B on gross investments and water price plus a comparison with observed values. A significant reduction in investment costs can be observed. The modelled values according to strategy B are to be compared with the observed values which would also result from a model run applying strategy A.

would have been the year 1976, when a minor shortage occurred. However, the original dimensions of the peak (which is now partly reduced due to the rules of strategy B) would have probably not been that big if strategy B would have been applied (we can assume that application of strategy B has not only short-term impacts but also long-term educational value for customers, which would lead to preventing the development of extreme peaks).

The effects of changes in infrastructure development on the cost structure are significant (Figure 6). Since significantly less capacity is built in scenario B than during the observed development (see Figure 2), less investment is required. The modelled and observed cumulative gross investments differ by about 60%. This seems a lot since it is known that mains account for at least 60% of overall investments. However, this difference is explained by three reasons. Firstly, specific investment costs in strategy B are lower (compared to past prices). Secondly, the main change in capacity development occurred between 1970 and 1996. During this period, few pipes were laid since the city no longer grew (only a few replacements were made). Investments in pipes were consequently minimal and most of the observed investment costs were due to the enlargement of waterworks, which did not occur with strategy B. Thirdly, inflation picked up significantly during this period, so that the difference in cumulative investments is further enhanced. Differing investment costs also affected the development of the water tariff (Figure 6). The simulated water price is considerably lower than the observed price. Note that the service fee (basic flat fee) is not included in the price shown.

This scenario indicates that best practice as applied in the past is not the only way to generate the required safe supply systems. The possibility of influencing consumers so that consumption peaks are avoided could provide an additional degree of flexibility while planning the systems. As utilities are confronted with inertia by those infrastructure that cannot be adapted fast if changes occur, it may pay to consider this additional degree of flexibility for future best-practice guidelines.

During the discussions of this scenario with the participating stakeholders it became evident that the question of the range of possible influences on consumer behavior remains of great concern. This is obviously a crucial piece of knowledge which is still missing in the water supply community. A second main concern is the fear of a capacity shortage if a pump failure reduces capacity even further. While considering a reduction of capacity, it appears to be a disadvantage that the system relies only on a few large waterworks. Capacity cannot be easily adapted due to the large impact of losing, say, one-third of the overall capacity immediately. It appears that a certain degree of decentralization increases flexibility in the case of renovation of the system.

CONCLUSIONS

The methodology of building a model based on rules of behavior of relevant stakeholders is a promising approach to provide the basis for discussing further improvements of water supply systems. This method is also a means to describe and quantify the mostly hidden, but probably influential, interests of participating stakeholders and to highlight the importance of incentives given by regulations. Through this approach emphasis is put on institutions shaping stakeholder behavior and less on technical details of the system.

The simulations of different scenarios of possible past and future developments raise the quantitative and qualitative awareness of the advantages and deficits of existing

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

best-practice 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 better adapted to today's situation. Because they are visualized by a model in a participative process, the findings can be effectively communicated to decision-makers or other stakeholders.

The modelled scenarios suggest, additionally supported by discussions with stakeholders, that the 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 it would have to be communicated effectively to consumers.

Ways of improving existing best-practice mechanisms may be to use the full range of available management tools: price incentives to manage average demand (a timescale of months to years) and information campaigns to manage short-term extreme events (a timescale of days). The main gains would be an increase in flexibility and adaptability to new developments. An additional result would be that the utility may demonstrate its efforts to achieve more efficient infrastructure use and thus gain public goodwill.

New strategies can only be put in place if the regulations and incentives given to stakeholders are adapted to ensure that implementation of the new target strategy simultaneously satisfies the interests of these stakeholders. Existing regulations and incentives should be rethought in the areas of:

- Tariff structure. The current focus is on the specific water price (cost/m^3 water used). This focus inhibits the introduction of demand-side management today, since utilities initially lose money if consumers use less water. As most of the costs of a utility are fixed, water tariffs would need to be subsequently raised to compensate for the unconsumed water (exception: the reduced consumption prevents new infrastructure from being built). Hence, in order to have an incentive to introduce demand-side management, the focus must be increasingly placed on the overall cost of the water service per year and utilities must gain more political room for maneuver with respect to water tariffs.
- Regulations. The regulations seem to be too inflexible. They demand that consumers must be able to use water at any time and in any amount. This does not leave a lot of room for utilities to introduce modern management means such as incentives to consumers to level out their water demand (i.e. reducing peaks).
- Information. Consumers should be better informed about the cost of the water they use. Otherwise there is hardly any incentive for them to save water or to help avoid peaks. A way to do this would be to have separate water bills (not concealed in other bills), and to increasingly install water meters for each apartment.

In summary, by considering institutional aspects such as incentives to and interests of stakeholders, current management strategies may be better understood and consequently also improved. The simulations run with a model developed in a participatory process illustrate the implications of current strategies and allow the exploration of further management changes. The approach chosen raises awareness and supports processes of social learning in a stakeholder group.

REFERENCES

Ajzen, I. 1985 From intentions to actions. In *Action-control: From Cognition to Behavior* (ed. Kuhl, J. & Beckmann, J.), pp. 11–39. Springer Verlag, Berlin.

Bakker, K., Downing, T., Garrido, A., Giansante, C., Iglesias, E., Moral, L., Pedral, B. & Riesco, P. 1999 *A Framework for Institutional Analysis*. *SIRCH Working Paper* no. 3 (Tech. Rep.). Environmental Change Unit, University of Oxford, UK.

Burse, J. 2000 *Quicksilver: A Component-based Environment for Agent-based Computer Models and Simulations*. CASOS presentation, Carnegie Mellon University, Pittsburgh, July 2000. http://dolly.interway.ch:8100/hp/quick00/quicksilver.pdf

Dahrendorf, R. 1958 Homo sociologicus. *Ein Versuch zur Geschichte, Bedeutung und Kritik der sozialen Rolle*. Westdeutscher Verlag, Berlin.

Edwards, W. 1954 The theory of decision making. *Psychol. Bull.* **51**, 380–417.

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest

Finger, M. & Allouche, J. 2001 *Water Privatisation: Transnational Corporations and the Re-regulation of the Water Industry*. Spon Press, London.

Gilbert, N. & Troitzsch, K. G. 1999 *Simulation for the Social Scientist*. Open University Press, Milton Keynes.

Grimble, R. & Chan, M.-K. 1995 Stakeholder analysis for natural resource management in developing countries. *Natural Res. Forum* **19** (2), 113–124.

Guy, S. & Marvin, S. 1996 Transforming urban infrastructure provision – the emerging logic of demand side management. *Policy Stud.* **17** (2), 137–147.

Jager, W., Jannssen, M. A. & Vlek, C. A. J. 1999 *Consumats in a commons dilemma (Tech. Rep.)*. Centre for Environmental and Traffic Psychology, University of Groningen, The Netherlands.

Langton, C. (ed.) 1989 *Artificial Life*. Addison-Wesley, New York.

Minsch, J., Feindt, P.-H., Meister, H.-P., Schneidewind, U. & Schulz, T. 1998 *Institutionelle Reformen für eine Politik der Nachhaltigkeit*. Springer Verlag, Berlin.

Nunes Correia, F. & Krämer, R. A. 1997 *Institutionen der Wasserwirtschaft in Europa* vol. 1. Springer Verlag, Berlin.

Ostrom, E. 1986 An agenda for the study of institutions. *Public Choice* **48**, 3–25.

Tillman, D. E. 2001 *Stakeholder Analysis in Water Supply Systems*. *PhD thesis*. Schriftenreihe des Instituts für Hydromechanik und Wasserwirtschaft. ETH Zürich, Switzerland.

Tillman, D. E., Larsen, T. A., Pahl-Wostl, C. & Gujer, W. 2001 Interaction analysis of stakeholders in water supply systems. *Wat. Sci. Tech.* **43** (5), 319–326.

Downloaded from http://iwaponline.com/jh/article-pdf/7/1/41/392691/41.pdf
by guest