Twenty years of asset management research for Dutch drinking water utilities

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ABSTRACT

This paper gives an overview of the asset management landscape on drinking water in the Netherlands and twenty years of research on this topic executed by KWR in close collaboration with water companies. A description is given of research questions and the international developments in the field of asset management. This is followed by the developments on asset management at the Dutch water company Evides. Twenty years of asset management research at KWR is presented in five phases, showing a transition from the question of how can the concepts of asset management help to better plan the replacement of distribution networks, towards integrated decision making on the asset system as a whole. A focal point for research could be how research can contribute to creating value for water companies. More formal information and improved modelling will continue to play a central role; however, attention is required for making use of expert knowledge, scenario building, data quality and the integration of information of technical, financial and societal origin.

Key words | applied research, asset management, decision support, information systems

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RESEARCHING ASSET MANAGEMENT

The widely accepted definition of asset management as stated in ISO 55000 is the coordinated activity of an organization to realize value from assets (ISO 2014). ISO 55000 further clarifies that asset management does not focus on the asset itself, but on the value that the asset can provide to the organization. Konstantakos *et al.* (2019) see as the main advantage of the ISO 55000 standard that it provides a basis for discussion and improvement derived from experience and methods that have been widely acknowledged and approved.

The above definition of asset management has a more generic angle and challenges utilities to define the strategic purpose; that is, the value of assets for the organizations and their stakeholders. The value (which can be tangible or intangible, financial or non-financial) will be determined by the organisation and its stakeholders, in accordance with the organisational objectives. Woodhouse (2018) clarifies the different perceptions of value and benefits associated with assets and their life cycle management. Woodhouse also provides a conceptual formula for calculating total value, as being the aggregation of:

- the asset capital value, defined as the total costs of replacement;
- a functional performance value multiplied by the remaining economic life, where:
  - functional performance value, comprising capitalised quantitative and qualitative usage benefits, minus total operating costs;
- a risk value multiplied by the remaining economic life, where:
  - risk is defined as the capitalised sum of known opportunities and threats;
- capitalised intangible or perception benefits.

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This structured way of looking at value promotes an agenda for improvement and research, consisting of issues like: how to achieve reliable figures for capital value, how to express performance and risk, how to define the remaining life and how to quantify (monetise) intangible aspects for stakeholders.

DEVELOPMENT OF ASSET MANAGEMENT IN AN INTERNATIONAL CONTEXT

How asset management has been implemented depends on the typical geographical and regulatory circumstances. Amaral *et al.* (2017) describe how asset management within the water sector has evolved and provide typical descriptions for a number of countries. In Australia and New Zealand and in England and Wales, asset management was developed as a reaction to the government's policy for achieving greater efficiency and customer trust. Also in the USA and Canada, governmental organisations encouraged asset management practices. Amaral *et al.* (2017) provide a number of research projects funded by the European Union with the aim of creating a sound and systematic asset management approach to assist water utilities in the establishment of a rational framework for rehabilitation plans of water and wastewater networks. In the Netherlands, the water company's shareholders (mostly municipalities and in some cases provinces) focus on low tariffs, and water companies adopted asset management mainly to become more efficient and transparent and to get a grip on the expected large-scale replacements of distribution mains.

ASSET MANAGEMENT AT EVIDES

Evides is the second largest drinking water company in the Netherlands. It supplies drinking water to two and a half million inhabitants and industrial water to large industries in the South-West of the Netherlands, including the city and port of Rotterdam. Evides uses predominantly surface water from the river Meuse, treated at one centralized plant.

Evides introduced Asset Management officially in 2009 with the objective of optimising the total cost of ownership (both CAPEX and OPEX) while maintaining an agreed level of performance. During the first phase, the foundation for asset management was laid with the focus on defining roles and decision procedures on a strategic, tactical and operational level. Also a system of key-performance indicators and associated reporting tools was established.

As of 2011, more focus was given to predicting future investments. With regard to the distribution of drinking water, investment analysis shifted from being driven by external parties (reactive approach) to being driven by internal analysis (proactive approach), taking into consideration the expected life and the impact of failure on the company's values. With regard to the abstraction and treatment of water, the focus was on identifying vital installations and predicting the end of their technical life.

Particularly for distribution, better analytical tools and methods were required. This raised the awareness of the need to improve data quality. Currently, a number of projects are under way to improve the quality and availability of the data. Additionally to the Joined Research Program, Evides started an internal research programme for exploring, amongst others, future treatment concepts. These concepts should enable Evides to considering the system from source to tap and anticipate future water quality challenges like viruses, medicine residuals and diffuse pollution due to agriculture.

Better-founded plans, including the required capital costs, help Evides to establish realistic scenarios and to evaluate these considering performance, risk and costs (CAPEX and OPEX). Although regulation in the Netherlands is less strict than it is in countries like the UK, Evides is increasingly taking governmental and societal aspects into consideration. This results in more emphasis on efficiency and effectiveness, benchmarked on issues like cost, customer satisfaction, interruption of supply, water quality and sustainability performance indicators.

Currently, Evides is putting considerable effort into cooperation with partners on replacing distribution infrastructure. This cooperation with fellow network operators and municipalities requires an ever closer collaboration, not just on the scale of a single project, but on an entire programme considering a large number of projects over a number of years. This cooperation results in long-term relations with contractors, providing them with more certainty and continuity. In addition to these developments, the company is exploring the impact of the energy transition on asset management. This will potentially result in infrastructure interventions, such as demobilisation of gas pipes, construction of networks for heating and cooling and an increased capacity for electricity grids. The energy transition and associated changes could also have a huge impact on the water distribution network. These challenges are to be combined with adaptations for climate change and transformation towards a circular and low-CO_2 society. In order to be proactive, Evides invests in more knowledge on the current assets and their resilience towards a rapidly changing and more demanding future.

RESEARCH ACTIVITIES ON ASSET MANAGEMENT IN THE NETHERLANDS

The ten Dutch and one Flemish drinking water companies are shareholders of the water research institute KWR. These water companies and KWR work closely together to co-create the so-called Joined Research Programme and its outcomes. This research programme is redefined every five years and consists of a number of research themes selected by the partners. KWR executes research in close collaboration with water companies and, when feasible, water companies implement the research results co-created by the partnership. Emphasis is on translating scientific knowledge into applicable, practical solutions for end-users. One of the research themes focusses on asset management.

Within the last 20 years covered in this paper, five periods can be distinguished that coincide with the funding periods of the Joined Research Programme. Several projects, for which references in English are available, are introduced. In 2006, KWR became an independent organisation. Before this year it was a part of Kiwa, meaning that references are made to Kiwa. The numbers between square brackets correspond to the conceptual model presented in Figure 2.

The start: before 2002

In 1997, a project was undertaken focusing on distribution network management that provided a conceptual model of all components required for taking balanced management decisions (Rosenthal *et al.* 2000) [1]. The project and the associated report raised awareness of the network as a system. Furthermore, it emphasised the requirement to focus on the performance of the entire system and the need for replacement, rather than on the behaviour of a single pipe. Although not mentioning the term asset management explicitly, this report is considered as the first step in focusing on asset management and corresponding research requirements. Under the term of distribution network management, research in the nineties was conducted on designing self-cleaning networks (Vreeburg *et al.* 2009; Vreeburg 2010) [2] and effective cleaning of mains (Slaats *et al.* 2004a) [3]. The first document by KWR using the term asset management originates from 2000.

Defining concepts of asset management: 2003–2007

In the period from 2003 to 2007, the focus of research was on exploring and defining the concepts of asset management, including defining organisational roles (strategic, tactical and operational), and on quantifying performance. An overview of the research was presented at the first LESAM conference in San Francisco (Beuken *et al.* 2004) [4]. As an important enabler for introducing asset management, water companies wanted to be able to measure the performance of supply. This resulted in the concept of Substandard Supply Minutes (Blokker 2006) [5], which is the main performance indicator for measuring the quality of supply and is used in national benchmarking.

In this period, destructive condition assessment methods for cast-iron and asbestos cement pipes (Slaats *et al.* 2004b) were introduced and described [6]. However, it became clear that the value of these tests was limited, as only a local result is obtained and the condition of individual pipes varied substantially. Research on the condition of PVC pipes has been carried out by KWR in cooperation with other research institutes in the Netherlands, manufacturers of PVC pipes, and suppliers of raw material. The conclusion was that the lifetime of existing PVC drinking water mains in the Netherlands will be at least 100 years. This is true under the condition that the internal and external loads do not result in hoop stresses exceeding 12.5 MPa and that no micro-cracks and mechanical damages are present (Breen 2006) [7].

For isolating sections in case of incidents and repairs, the reliability of valves is crucial. Unreliable valves have a high impact on the number of customers affected. KWR has developed a method that translates the reliability of individual valves to the reliability of the network. The methodology is encapsulated in the OptiValves software, which is a risk-based tool that takes into account the probability of valve failures and their impact on customers. The tool helps water companies to optimise valve maintenance programmes and to enhance network design (Trietsch & Vreeburg 2005) [8].

Risk analysis plays a central role in asset management decision making. In collaboration with water companies, a project was executed in which a risk matrix for pipe failures was established. Different classes for consequence of failures were defined, including a subdivision into five categories. Based on failure data (likelihood of failure), OptiValves (affected customers), hydraulic modelling (pressure reductions and hydraulic disturbance) and GIS (costs and external damage), all valve sections were positioned into the risk matrix and critical sections were identified. This research made clear that quantitative risk analysis is a feasible method for identifying critical mains sections in water distribution networks. The results and the used methodology are described by Beuken et al. (2008) [9].

In this period, field observations were collected from the networks that were constructed using the self-cleaning principles. Field measurements (particle counting, flow measurements and flushing experiments) showed that no accumulation of particles took place in self-cleaning networks (Blokker et al. 2007) [10]. Furthermore, cost savings were reported for construction due to shorter lengths and smaller diameters as well as for operation, as no flushing was required.

Start of making use of improved data: 2008–2012

The focus of the research period from 2008 to 2012 was on condition assessment, risk analysis and performance measurement of distribution networks. In this period, water companies applied predominantly asset management methods to water distribution networks. Information systems became more mature as improved software for enterprise resource planning, GIS and asset registers became operational. This development resulted in more and better quality data. The use of digital devices by pipe fitters enabled an easier and better controlled process for the registration of pipe failures. In 2009, five water companies started to register pipe failures in the USTORE database. Initially, data on failures and the network assets were stored in spreadsheets (Vloerbergh & Blokker 2010) [11]. In 2010, the USTORE web platform was launched enabling water companies to upload data into a database. In the same year, two more water companies joined USTORE.

Information on the condition of large-diameter pipes can be obtained by mains inspection. In Beuken et al. (2011), different options for inspections were described and inspection with the Acoustic Resonance Technology of a 300 mm cast-iron main was described in detail [12]. The report also provided business cases indicating that, in addition to technical limitations of the in-line inspection technology, it can only be applied cost-effectively for 300 mm diameter and larger pipes.

A simplified formula is being applied in the Netherlands to calculate the so-called erosion craters (pits resulting from a pipe burst). By using this formula, a buffer zone is calculated around pipes, which is used to identify what objects are potentially prone to damage in case of a pipe burst. This formula is rather conservative, resulting in large buffer zones. This is unfavourable for water companies, since a large buffer zone means that high impact objects (dykes, highways, important buildings, etc.) could potentially be affected. A more realistic formula, resulting in smaller buffer zones, means that fewer mains are in high impact areas. Such a formula is available; however, it requires extensive computation, combining GIS and all-mains hydraulic models. In van Daal et al. (2013), the adopted method and a case study are presented [13]. This research shows that more complex computation can help water companies make more realistic asset analyses. In this example the additional computational complexity resulted in a decrease in the number of high-risk mains.

In this period, water companies were also approached by various software distributors offering decision support software packages for mains replacement. As the water sector wanted an objective opinion on these products, KWR was engaged to assess potential results and the necessary requirements for their use. Several workshops were organized in 2010 to allow several software companies to present their solutions. Subsequently, pilots were organised with water companies whereby these packages were applied and assessed. Results of these pilots can be found in Beuken & Blokker (2013) [14]. The main conclusion of these pilots was that the available operational input data and the strategic considerations (often applied as weights) were not yet sufficiently mature to obtain reliable results.

Intensifying and broadening asset management research: 2013–2017

In addition to the application of the concepts of asset management to water distribution networks, the Dutch water companies wanted research to be expanded to developing and applying those concepts to the areas of water abstraction and treatment.

Starting in 2009, water companies uploaded failure registration data to the USTORE database. This allowed more statistically reliable analyses. For some examples of such analyses, see Moerman *et al.* (2017) and Castro Gama *et al.* (2018) [15]. Besides failure registration, information on the likelihood of failure can also be obtained by mains inspection. In order to validate different inspection technologies, inspections with in-line radar, E-Pulse and destructive testing were evaluated. The results of these inspection technologies are rather comparable (Beuken *et al.* 2015) [16]. Water companies applied non-destructive (local) inspection on pipes that became available during repairs or replacements. This resulted in a great amount of condition data. Comparative results, however, showed that the representativeness of the condition data is rather limited due to the large variability of local deterioration processes. To get more reliable insights, in-line measurements of the condition of smaller mains are required. As in-line inspection is not feasible, the applicability of autonomous inspection robots was considered. Based on the literature survey and laboratory experiments, a prototype of an inspection robot was created. This robot could stay permanently in the network and is able to self-propel, taking note of obstacles (Maks *et al.* 2017) [17]. Based on this research, a new project started to bring an autonomous inspection robot to market.

Inspection data provides water companies with detailed information on the network, like the actual network characteristics, the residual wall thickness or the gap at joints. To define the condition of pipes, it is necessary to combine the results of these measurements with a computation of the allowable stresses on mains. These stresses are caused by a combination of loads imposed by the water pressure, the soil (included soil movement) and traffic. The software package Comsima was developed to compute the stresses in the pipe wall for an entire network (Wols *et al.* 2018) [18]. The results of this package have been validated with the help of failure data from USTORE, and have been shown to be reliable.

Data from many different sources is used to quantify the risk associated with water distribution networks. For obtaining a reliable prediction of the likelihood of failure, now and in the future, results from failure registration, various inspection techniques and a package like Comsima can be combined. These different sources of data all have uncertainties associated with them. The uncertainties can be input related, like the variation of measurements, inaccuracy of measurement or incompleteness, or calculation related, due to incorrect relations or simplifications. Often, the result of decision support software is a single answer, either failing to account for uncertainties or not showing them explicitly. As a consequence, 'safe guesses' are applied frequently, resulting in conservative and expensive outcomes. The concept of UKNOW has been established to obtain a conceptual framework for data combination and targeted data improvement by making uncertainties explicit (Blokker *et al.* 2017) [19]. By using this approach, water companies can focus activities on improving decision making. The focus is placed on those data sources where actions for data quality improvement have the largest impact on reducing inaccuracies. This means that the result of a computation is rather an area in a risk matrix than a discrete point, see Figure 1. In this example a water company is advised to reduce the risk of the asset relative to the purple oval area and to reduce the uncertainty of information on the asset relative to the blue oval area.

The design and construction of entirely new networks is rare in many developed countries, including the Netherlands. Replacements are generally small adaptations in an existing network. These replacements are also an opportunity for considering an improved hydraulic design. A 'network blueprint' approach helps water companies plan replacement interventions. Blueprints depict an ideal

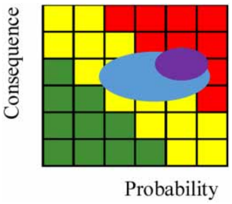

Figure 1 | Representation of an asset in a risk matrix, taking uncertainty into account. The blue oval area represents a lower risk with a higher uncertainty, the purple oval area a higher risk with a lower uncertainty. The full colour version of this figure is available in the online version of this paper, at http://dx.doi.org/10.2166/ws.2020.179.

design of a water distribution network from an integral performance perspective. An optimisation problem is then formulated based on the company-specific objectives and constraints, considering also the existing infrastructure. Once a blueprint is determined, the question arises on what is the optimal transition path from the current infrastructure to the blueprint. Both optimisation problems are solved with Gondwana, a generic software platform for the optimisation of drinking water distribution networks (Van Thienen & Vertommen 2015). Vertommen *et al.* (2018) describe an application of this approach showing that the costs for the optimised blueprint can be as low as 64% with respect to those associated with the existing infrastructure, while the hydraulic performance is improved [20].

The evaluation of decision support software packages for mains replacement, as described in the previous period, has been further analysed. This time it involved the application of four packages on the same network (Beuken *et al.* 2016) [21]. In this case study, the packages used the same data on mains and failures (the network of The Hague and surroundings). The packages all provided the same total length of candidate pipes for replacement. Comparing the individual mains proposed by these tools, however, showed large differences, raising questions about the quality of the selected replacement solutions. These differences are mainly a result of the modelling approach and interpretation of data, especially the assignment of failures to groups of mains and the extrapolation of the reported failures into expected future failures.

During this research period a more integrated approach for asset management was sought, applying asset management also to assets for (ground) water abstraction and treatment. Asset management for treatment works (including pumps and reservoirs) seemed to be more challenging than for distribution networks. This was due to the uniqueness of individual treatment processes and installations, where the design and operation are adjusted to the water quality of the source. Where a distribution network is described by a handful of different asset types, a treatment plant counts hundreds of them. Furthermore, data availability is a challenge as the Dutch water companies want to apply the concepts of asset management to treatment plants but are still setting up asset registers. Therefore, a database on asset failures similar to that for distribution networks is much more difficult to establish. Another challenge is the lack of a clear indicator on the quality of performance, such as customer minutes lost in water distribution networks. In some cases risk analyses have been applied, but companies are often reluctant to follow them because of the huge administrative burden for setting up such an analysis. Research done by KWR was focussed on making quantitative fault tree analysis and knowledge exchange on risk analysis and operation.

Asset management for groundwater abstraction wells appeared to be easier to implement, as most of the well systems have a rather uniform design. Research into clogging of wells done at the beginning of this century (see Van Beek 2010), showed that clogging due to particles could be prevented by switching pumps on and off on a regular basis. Clogging due to accumulation of chemical precipitates, however, may be best prevented by continuous abstraction [21]. The knowledge of those phenomena has been implemented into the operation of well fields. Within asset management research, methods were described for monitoring clogging behaviour and the regeneration of clogged wells. Switching procedures have been optimized, balancing between a stable water quality performance and minimized costs for regeneration.

Current research

In the current research period, which started in 2018 and will finish in 2023, asset management research is executed following two pathways. Research topics of a mono-disciplinary nature are considered in a disciplinary theme (such as abstraction, treatment and distribution). The complementary theme of Integrated Asset Management covers topics that transcend disciplinary themes and focusses on integrated decision making. Also, attention is given to the semi-public role of water companies and the involvement of stakeholders into decision making.

The mono-disciplinary asset management research in the distribution theme focusses on deterioration processes of PVC and asbestos cement mains, a statistically representative method for extrapolation of monitored pipe failure frequencies towards future performance and network blueprints. The projects make use of more data becoming available, for example failure data from the USTORE database, condition data from pipe inspections and data from various GIS sources. In the theme focussing on groundwater abstraction, guidelines for well operations are further being developed.

The overarching goal of the Integrated Asset Management theme is to develop a framework for integrated decision support, taking into account:

- internal factors, with a focus on reliable information for decision making, the link between activities and the company's strategic objectives, risks and integrated performance measurement and risk analysis;
- external factors, with a focus on the most relevant stakeholders, targeted communication to stakeholders and the creation of societal added value and sustainable solutions;
- future developments, with a focus on increasing stress on assets at surface and subsoil level, adoption of new technologies, changing demography and patterns of water use and decentralized water systems.

Currently, three research projects are under way focussing on: (1) integrated decision making, (2) linking customer expectations to asset management decisions, and (3) the impact of future trends reported in earlier research on asset management. As part of the fourth project, workshops are organized in which drinking water companies and KWR exchange knowledge and experiences on integrated asset management and in which requirements and possibilities for the development of a framework on integrated decision support are discussed.

THE PORTFOLIO OF ASSET MANAGEMENT RESEARCH

Most water companies use the risk matrix as the central planning instrument for asset management activities, considering performance, costs, and externalities as boundary conditions. In Figure 2, a conceptual model is shown of the coherence of asset management by water companies and corresponding research.

WATERSHARE

Knowledge institutes all over the world work on similar issues in the domain of the design and management of

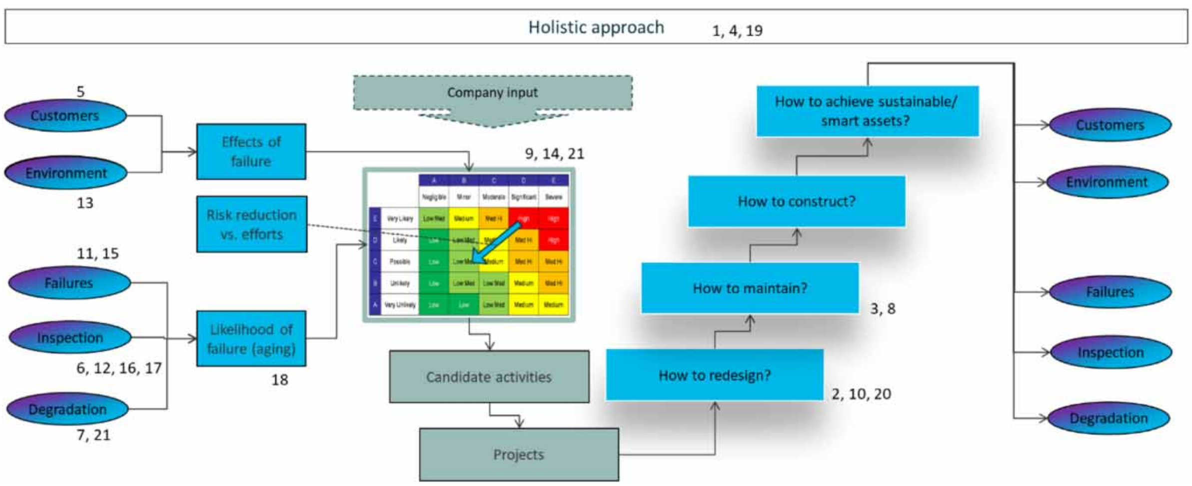

Figure 2 | Conceptual model representing the coherence of asset management by water companies and corresponding research. At the left, the observed reality is shown. Based on research water companies are able to translate reality into input for the risk matrix. The reduction of risk in relation to the required efforts generates candidate activities, which can result in projects. Research questions related to these projects are based on (re-)design, maintenance, construction and the achievement of sustainable and smart assets.

infrastructures for the provision of water. They deal with the same developments and needs – for example, demographic changes, climate issues, ageing assets, scarce resources, demands for more sustainable strategies and operations. But the knowledge produced is frequently fragmentary in nature and not accessible to all. Worldwide, knowledge institutes feel a responsibility to work together on bringing the best knowledge available to water practice. In 2012, KWR Water Research Institute set up Watershare to make this possible.

Watershare is an international collaboration in which water sector-proven methods, techniques and experiences are shared and applied. Watershare's objective is to make the most appealing and effective knowledge and expertise internationally available to water practice. Watershare is a consortium of currently twenty of the world's most reputable water research organisations and water companies, who share the goal of applying high level global knowledge and expertise to local water challenges.

The members of the Watershare community see their task as being to make new knowledge available in the form of practical tools of relevance to water practice. A number of the researches mentioned in this article have resulted in Watershare tools. These tools are listed at the end of this paper.

LINKING RESEARCH TO VALUE FOR WATER COMPANIES

Asset management is about creating value, and research on asset management should help achieve that goal. The components for defining value, as given by Woodhouse (2018) and mentioned in the beginning of this paper, help set the agenda for research. Where asset value is an issue that is mostly addressed by water companies, the other aspects (remaining life, functional performance, risk and intangible benefits) are research areas that are or have been covered in the research programme of KWR. Two subjects are to be mentioned explicitly. Firstly, the UKNOW concept, where uncertainties in decision making are taken into consideration as a starting point for a discussion of added value of information, leading to a trade-off between improved decisions and costs for improved information. Secondly, the issue of intangible benefits, and costs, which is addressed in the current integrated asset management research focussing on, amongst others, customer expectation and stakeholder involvement.

The development of asset management at Evides clearly indicates a transition of defining what asset management is, and what it means for the organization, towards improving the data systems, towards modelling technical performance (end-of-life), towards defining the system as such, and its role in a changing environment. It is this transition that can also be distinguished in the twenty years of asset management research conducted by KWR and thereby demonstrates its value for water companies.

LESSONS LEARNED

Looking back at twenty years of asset management research, the most important lessons learned are as follows:

1. The drinking water companies participating in the Joint Research Programme feel an increased urgency for an integrated model-driven approach. This will enable them to transition from organisations based on expert knowledge into those based on formal information systems and being able to make use of new technologies and complex decision support models.
2. Where the drinking water companies considered future developments mostly as extrapolations from the past, it is now felt that the future is unpredictable and that the paradigm of supplying drinking water will change. Asset managers should therefore not try to rebuild existing assets but focus on redesigning them according to a set of future states.
3. Developments in the field of information management and methods for analysis will result in more good-quality data and better based decisions. Promising developments in the KWR research are, amongst others:
    - optimisation techniques (the Gondwana platform) for asset management planning;
    - machine learning for a better understanding of pipe breaks, and

- building digital twins for analysing the asset management system as a whole, subject to various future scenarios.

4. Obtaining objective, representative and complete data sets is crucial for a better management of assets. This is, however, a time-consuming task and the need for data of appropriate quality is often not sufficiently understood. Moreover, water companies prefer to make use of data that is opportunistically available rather than based on systematic and targeted data collection.
5. The problem of aging assets continues to play an important role in asset decisions. Condition assessment and definition of a risk-based residual life remains a crucial aspect. This is especially true for complex and tailor-made installations.
6. Financial figures are used for business case and scenario evaluations. Effective asset management will only be possible when water companies possess detailed figures on capital and operational expenditure, as well as on the cost of failure or interruptions to supply.
7. Water companies apply registration on asset performance. These registration activities serve merely for organisational issues; that is, they provide instructions for maintenance activities. A secondary use of these activities is for asset performance analyses. These analyses serve the more long-term purpose of accessing the system behaviour for defining, amongst others, risk-based inspection or scenario analysis. This is done less frequently. It also appears that these analyses require much higher levels of data quality and that considerable cleansing activities are required to perform these more detailed analyses.

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