1

What do we Mean by 'Smart Water?'

Introduction

This chapter considers and defines the terms and expressions associated with 'smart water' and places them in the context of water management in the broadest sense. It also presents a range of estimates and forecasts of smart water's market size and its share of the markets associated with water management and environmental goods and services in general.

1.1 Defining 'Smart'

1.1.1 'Smart' and Utilities and Public Services

When applied to utilities, environmental and public services, a working definition for 'smart' would be the application of data monitoring, transmission, management, and presentation to services in a manner that enhances the efficient use of their operating assets.

It covers data management and communications systems and services (ICT – information and communication technologies) for utilities public and environmental services. It can be seen as a catchier alternative to 'intelligent' which has also been applied here.

1.1.2 Smart Consumer Goods

In addition, 'smart' has been adopted for a wide variety of consumer goods. In November 2002, Microsoft announced that it was developing the Smart Personal Objects Technology (SPOT) Initiative, for 'improving the function of everyday objects through the injection of software' (Microsoft, 2002). While a range of devices were released by third party manufacturers (wristwatches, GPS navigation systems and weather stations) SPOT was discontinued in 2012, in particular due to the development of WiFi as a more efficient data transmission system (Gohring, 2008). Since then, 'smart' mobile phones, tablets, watches and cameras have been launched, along with TVs and cars under development.

Smart Water Technologies and Techniques: Data Capture and Analysis for Sustainable Water Management, First Edition. David A. Lloyd Owen.

As will be discussed later, the migration of 'smart' into consumer goods such as washing machines, showers and lavatories is set to become a factor in domestic water demand management as the 'Internet of Things' (IoT) connects domestic devices into broader data networks.

1.2 'Smart Power' and 'Smart Grids'

Smart power management for electricity utilities has not been driven by one or a small series of dramatic or disruptive events; it stems from a gradual continuation of demand management approaches. Electricity metering for measuring electricity used was introduced in the 1880s and has been developed ever since, including the introduction of digital metering in the 1990s (Anderson and Fuloria, 2010). Smart electricity metering is being driven by utilities and legislation, especially in the European Union, where at least 80% of meters are meant to be smart by 2020 (European Union, 2009).

Smart electricity meters inform electricity consumers how much power they are using and how much this is costing. Differential daily tariffs can be exploited to take advantage of when it is cheaper to use electricity (the lower the peak level of demand, the cheaper it is overall to produce each unit of electricity) which in turn means that the utilities can smooth out their power generation more than when there is only a single tariff. This approach is a modern refinement of night storage heaters, which have been used for some decades, assisting users to consider when they use electricity for light, heat and hot water and to optimise the time when these are used, to smooth their power demand profiles.

1.2.1 Smart Grids

Electricity grids, whereby utilities link up various power generators into a network offering greater security of supplies and flexibility of capacity were developed in Europe and the USA in the first three decades of the 20th century. In the UK, the Electricity (Supply) Act of 1926 brought about the Central Electricity Board, which rationalised 600 local power generators into regional networks by 1933 which in turn were integrated into the National Grid in 1938 using the 132 most efficient power generators in the UK.

The smart grid is concerned with ensuring the most efficient use of electricity across a network, so that no more generating capacity is deployed at any one time than is needed, matching demand with supplies as closely as possible and ensuring that both the most appropriate generating capacity is deployed (using generators at their optimum output) and with minimal transmission losses. They are also intended to provide the most reliable service under given circumstances and more recently to lower the utility's environmental impact through renewable energy sources.

According to the Smart Grid Forum (Smart Grid Forum, 2014), a smart power grid is 'a modernised electricity grid that uses information and communications technology to monitor and actively control generation and demand in near real-time, which provides a more reliable and cost-effective system for transporting electricity from generators to homes, businesses and industry.'

Smart electricity grids were made possible by advances in data capture, communication and management through advances in computing, data transmission and metering

in the 1980s and 1990s. The first major deployment was in Italy, where the Telegestore programme was launched in 1999 and was completed by 2006, resulting in a comprehensive smart grid and metering infrastructure. Efficiency gains meant that operating spending per customer fell from €80 in 2001 to €49 by 2008 (Drago, 2009). In social (Google) and technical (IEEE Xplore) media, the frequency of the use of 'smart grid' entries becomes increasingly frequent from 2008, with the first journal citation having taken place in 1997 (Gómez-Expósito, 2012).

1.3 Cleantech and Smart Cleantech

The expression 'Cleantech' ('CleanTech' and 'Clean Tech' are also used) is an abbreviation of clean technology. Cleantech covers goods and services that are designed to reduce the environmental impact of utility, environmental and public service activities such as power, waste management, heating and transportation, along with consumer goods associated with these such as washing machines and cars. Cleantech's driving principal is, wherever attainable, to 'do more for less' whereby an innovation both improves the performance of a utility or an allied service, and lowers its costs. It is thereby seen as helping to make essential goods and services more affordable while also improving the efficiency of goods and services and reducing wastage to a minimum.

In practical terms, Cleantech covers goods and services that maintain or improve productivity while lowering energy and material resource needs and lowering operating and manufacturing costs. This is typically brought about through improving efficiency, minimising the resource intensity and reducing the carbon footprint of these offerings. By bringing down the costs of these goods or services, their affordability is also improved, allowing for a more extensive adoption than was possible with traditional approaches.

In the author's experience, there have been three factors behind the term's popularity. Firstly, in the late 1980s, the expression 'environmental services sector' was initially adopted by the financial services sector for companies involved in waste management, environmental consultancy and contaminated land remediation. The water and sewage sectors were at the time regarded as utilities, and with some exceptions, the impact of environmental drivers on their activities had a low priority. Secondly, in the early 1990s, companies involved in providing environmental goods and services were considered 'recession resistant, if not recession proof'. During this period (for example there was a recessions in the USA in 1990–91, the UK in 1991–92 and Japan in 1991–93) it became evident that a decline in house building and decreased industrial activity did in fact significantly impact the environmental services sector and the expression lost its attraction to investors. Finally, the succinctness of the term and the way it allowed other applicable activities to be included (in particular, responses to climate change) made it an attractive expression for those involved with the industry in subsequent years.

Cleantech is in particular associated with aiming to decrease a product or service's environmental footprint, typically in terms of its CO_2 generation. The ultimate aim here is to 'de-carbonise' activities so that they are not net generators of CO_2. As a result, Cleantech is especially associated with developing and deploying renewable energy technologies.

1.3.1 Smart Cleantech

Smart Cleantech can be seen as an overlay of information processing upon extant systems. For example, the smart grid is the next stage of the adoption of smart Cleantech approaches, that of linking disparate activities together to that they can be monitored and managed in a more efficient manner than before. All aspects of Cleantech can potentially benefit from smart approaches where they enable the impacts of these innovations to be delivered in the most efficient manner.

Along with the smart grid, smart Cleantech is concerned with the automation of systems within Cleantech, managing their interfaces, ensuring that they are self-healing (for example, through negative feedback loops), by adopting integrated communications for monitoring, supervisory control and data acquisition (SCADA) and delivering usage optimisation and peak demand smoothing. These terms and their potential applicability will be considered in due course.

The principle of 'doing more for less' is particularly important in the water sector, which has greater funding challenges than other utilities. Smart water approaches will only be adopted if they allow water utilities and other users improved performance and service delivery and assist them to lower their capital and operating costs.

1.4 Smart Water

Smart water is a term derived from the 'smart metering' and 'smart grid' sides of the Cleantech industry for lowering electricity usage and making power distribution more effective and efficient. In terms of water, this covers water distribution and usage, wastewater distribution, treatment and recovery, and also covers water flows, quality and saturation in the built and natural environment. It is a concept that has been realised through the development and convergence of information technology, mobile and digital communication and the Internet.

Smart water 'is something of a catch-all expression' (OECD, 2012) for the current and potential impact of data collection, transmission and analysis for water and sewage utilities and domestic, commercial, industrial and irrigation users. As with the smart sectors previously described, smart water is in essence about achieving more while spending less. Despite being a part of water management in various forms for the past decade, in practical terms 'its definition and role remains a work in progress' (OECD, 2012). It is not intended to replace how services have been operated, rather to improve them and therefore to become 'an enabler of innovation, as much as being an innovation itself' (OECD, 2012).

As a concept, smart water emerged from 'Cleantech' in general and 'smart Cleantech' in particular, respectively as a suite of technologies designed to minimise and mitigate the impact of human activities on the natural environment and the potential for information technology, data transmission and perhaps, in the future, for using the 'Internet of Things' (IoT) to further optimise the effectiveness of such approaches. This is a somewhat radical approach for, as far as water management is concerned, it is a typically conservative activity and in consequence smart water is still at a tentative stage of its development. Indeed, its potential contribution towards addressing key structural challenges facing water and sewage management has not yet been fully appreciated.

A degree of caution is necessary, as it is often tempting to perceive an emergent technology or application as a realised one. Mobile communications provide a useful analogy. In the 1980s and early 1990s, mobile communications were seen as a dynamic and growing activity providing voice and limited data services at a high price to 10% of even 20% of the adult population in the more developed economies. Instead of being a premium service, mobile communications have since evolved into a low cost voice and an increasingly sophisticated data service whose coverage is becoming appreciably greater than that of fixed wire telephone services, especially in developing economies.

There are two ways of considering smart water. Firstly the parts of the water cycle that it can impact and how that impact may be felt and secondly, how it can influence the management of each of these components.

1.4.1 Smart Water and the Flow of Information

Smart water management typically involves five discrete stages in information handling. Data collection, interpretation and management may take place by using approaches such as JCS (data cache management for optimal data handling), CRM (customer relations management via dedicated data management), smartphones as data handlers and GIS (geographic information systems for collecting, analysing and sharing geographic information).

The examples of technologies involved below are in part based upon Heath (2015).

1.4.1.1 Monitoring and Data Collection

A monitoring system that enables the real-time (or as near to real-time as is practicable and needed) monitoring of all the necessary information for the effective management of the water service concerned and the collection of the relevant data. For example, in the water distribution mains this would include water flow and pressure, as well as temperature, pH, turbidity and the presence of treatment chemicals and contaminants. The monitoring data is then collected into a form that is suitable for its transmission.

1.4.1.2 Data Transmission and Recovery

The closer to real-time the data collection is, the greater the necessity that the data can be transmitted without human intervention. For example, the move from manual to automated domestic meter reading.

Getting data in from a number of remote sites covering a water or wastewater network, domestic customers or surface waters requires remote data transmission from the field monitors to the data management centre. This can be carried out through fixed wire or wireless data transmission. Mobile data approaches are driven by the cost of transmitting the data in relation to the value accrued from this information. High value data from a remote point justifies dedicated data transmission, while lower value data such as domestic metering can at the most basic level be gathered by, for example, a drive-by wireless data collection service.

Data communication may be 'piggy-backed' on to electricity or telecoms networks, through radio transmission, or various mobile data applications.

1.4.1.3 Data Interpretation

Data is collected at a monitoring centre and is processed so that it is in a useable form for its manipulation and presentation. Given the volume of data generated, this needs to

be done on an automatic basis. One particular concern here is to ensure that all sources of potentially valid data can be accessed and that the system is open to accepting new data sources as they become available. The hybrid cloud (using private and public cloud-based data) may be used for integrating data from a wide variety of sources, such as water use, water demand, weather data and forecasts and monitoring external events what may affect water demand.

1.4.1.4 Data Manipulation

Data is interpreted according to each end-user's need. At this point, feedback loops may be used to feed new information into predictive models so as to be able to update any forecasts being generated and also to improve the model's predictive ability through the use of real-life information rather than simulated data.

1.4.1.5 Data Presentation

Finally, the information that has been gathered and analysed has to be presented in a manner which allows operators to act upon it in the simplest and most effective manner possible. This involves the use of graphics and alerts to inform an operator about any perturbations that ought to be of particular concern, while providing immediate access to the underlying data so that they can appreciate its particular nature. This may involve presenting information through a series of layers that allow operators to focus upon potentially relevant events and to locate and place them within their relevant operational context.

The first four stages can be seen as getting the data that a user needs, with the user acting on this data as presented in stage five. The object of stage five is to assist the user to make an informed decision based on this information. That may range from a domestic customer seeking to modify water usage to keep water (and electricity) bills down, a grower deciding when to irrigate crops or a utility manager considering which water resources to deploy.

The SWAN Forum (Smart Water Networks Forum, an industry group promoting the understanding and application of smart water management, swan-forum.com) defines data flow across smart networks (Peleg, 2015) as starting from the final outcome and working down to the infrastructure involved. They are as follows:

1) Automatic decisions and operations.
2) Data fusion and analysis.
3) Data management and display.
4) Collection and communication.
5) Sensing and control (including smart water meters).
6) Physical layer (including traditional and bulk meters).

Stages 2–5 are seen by the SWAN Forum as forming the smart water network.

1.4.1.6 From Top–Down to Bottom–Up; Inverting the Flow of Information

Smart water is redefining the way that information is gathered and in whose interest this information is gathered and where it goes. For example, data collection through smart apps on mobile phones allows people in developing economies to monitor their access to safe water and sanitation (and the presence or absence of open defecation) and send this information upwards, rather than relying on the traditional visitations of

government officials. Likewise, smart cash transfer approaches using mobile phones have both reduced customer time in paying utility bills and reduced the cost of billing for their utilities.

1.4.2 Smart Water and Managing the Water Cycle

Seven principal smart water applications can be identified. All of these are linked to some extent with the other elements.

1.4.2.1 Potable Water Systems

Optimising the beneficial use of water resources and managing water distribution networks to through minimising non-revenue water (NRW) and giving consumers tools to control their consumption, while maintaining the appropriate level of water quality and service delivery. This is delivered through a smart water grid and uses smart domestic metering, pressure management, network monitoring and remote leakage detection. Water use minimisation is based on the principle of demand management.

1.4.2.2 Sewerage Systems

Managing the sewerage networks and wastewater treatment works so as to minimise their net energy needs, the best application of assets for transporting and treating wastewater and minimising the environmental impact of the wastewater. This includes managing flows of municipal sewage, industrial effluents, and storm (rain) water and relating these flows to the systems' storage and treatment capacity. Applications include flow metering and network condition monitoring,

1.4.2.3 Energy Use and Recovery

Minimising the amount of energy needed across the water cycle through controlling energy use, optimising power consumption, and by using water and wastewater flows to generate electricity along with recovering energy embedded in the wastewater. This also extends to nutrient and water recovery from wastewater. This involves network, water treatment and wastewater treatment monitoring to minimise the amount of pumping needed, along with treatment chemicals required and optimising treatment processes for water, nutrient and energy recovery.

1.4.2.4 Smart Environment

The use of real-time monitoring allied with predictive systems to minimise the response time to any perturbations in each catchment area, including linking treatment works to the monitoring data. Demand management for municipal, industrial and irrigation applications is used to minimise the amount of water that needs to be abstracted from each catchment area, along with real-time monitoring of water flows through the catchment to maintain the integrity of the water cycle.

1.4.2.5 Flood Management and Mitigation

Real-time monitoring of rainfall, water flows, soil moisture, and groundwater levels are allied to comprehensive and fully updated data on the flood characteristics of each catchment area to respond to changing water levels and to maximise the time available to respond to potential flooding incidents.

1.4.2.6 Resource Management

Monitoring of surface water, reservoir and ground water levels and quality and to ally this data with current and anticipated water demand from various user types to ensure adequate water availability and to balance demand with the various resources available.

1.4.2.7 Integrated Water Management

Smart water systems offer the potential to deliver closed-loop systems for municipal and industrial customers through linking up the treatment, distribution and resource recovery processes outlined in the first six examples. The municipal applications would be based on localised systems, serving a smaller town or a sub-district within a larger utility. This involves distributed rather than centralised treatment facilities with an emphasis on minimising the energy intensity of the water and wastewater networks involved.

1.4.3 Smart Water and the 'Food, Water, Energy, and the Environment Nexus'

Smart water has a central role to play in the so-called food, water, energy and the environment nexus ('the nexus'), especially through water demand management and effluent resource recovery through the nexus. While it is an arresting expression, 'the nexus' may well be replaced by a more compelling expression in time.

Nexus-related themes include irrigation water for agriculture and other applications, nutrient recovery for fertilisers and energy recovery for treatment processes and export. Indirect impacts include lowering water abstraction and utility footprints. There are also direct and indirect interrelationships between resource recovery and the costs associated with maintaining and extending municipal water and sewage services. Water recovery also has an impact on demand and resource management through the impact water reuse on overall water abstraction.

1.5 Water, Smart Water and Cleantech

Water has sometimes had a somewhat uneasy relationship with the rest of the Cleantech sector. This stems from an assumption that pipes, sewers and treatment works do not naturally belong in a sector that is associated with photovoltaics, hydrogen cells and data systems. Such a view does not reflect the fact that water services, gas, telecoms, and electricity provision are utility activities. There are significant cross-linkages between utilities both in terms of services developed for one utility being adapted for another and where combined services can be offered.

As will be seen, water occupies a small section of the Cleantech sector in terms of funding flows and to a lesser extent in capital and operating expenditure, and the same applies with smart water and smart Cleantech. Compared with many sectors where Cleantech is being developed, water and wastewater are seen as slow moving and risk adverse, with some reluctance by municipal and domestic customers to increase up-front spending on their utilities, especially on innovative approaches. The challenge in funding associated with water utilities and services is in fact becoming a driver for water Cleantech in general and smart approaches in particular.

With their relatively small market size, water Cleantech and smart water have tended to be seen as an adjunct for other sectors, where extent technologies can be adapted to extend their market reach rather than looking for approaches that are specifically designed to serve the water sector. Likewise, other utilities and service providers are looking for opportunities in water and wastewater for technologies and techniques that were developed for applications in other sectors.

Other links with the rest of Cleantech are emerging through work on de-carbonising the water and wastewater sector, or making traditionally intensive actions such as water and wastewater pumping and wastewater treatment and recovery energy (and therefore carbon) neutral. Meanwhile, forms of automation are an example of utility services being adopted by other, while smart meters are being developed that combine reading and billing for water and electricity provision.

1.6 Disruption and a Conservative Sector

1.6.1 Why Water Utilities are Risk-Averse

Risk aversity and an institutionally conservative approach are characteristics of the water sector. Unlike for example electricity, water provision is directly affected by public health and environmental concerns. Water is usually expected to meet applicable levels of purity as well as service delivery expectations both in the reliability of water provision and in aesthetics such as taste and colour. Wastewater treatment and disposal is likewise affected by legislation affecting the way it is handled and discharged into the ambient environment.

In developed economies, any deviation from perfect water and wastewater delivery is considered as unacceptable. Shannon and Weaver (1949) pointed out that when information comes across steadily, it is not noticed (background music for example) until it stops. It is the deviation from a steady state that a consumer does not expect. In the case of water and sewerage, any deviation from a perfect service will be immediately apparent and therefore completely unacceptable.

While access to reliable telecommunications services are desirable and humanity can exist without electricity (albeit, with an even greater loss of utility) access to potable water is essential to life, while the economic and public health costs of poor access to water and inadequate sanitation are considerable.

Another factor is the asset intensity of water services – and even more so for sewerage – in relation to the revenues their activities generate. This leads to concerns about stranded assets, whereby innovation obliges a utility to acquire new systems even though it already has perfectly functional assets. For example, if manual read water meters were recently purchased, this may delay the adoption of smart meters because of the concerns about purchasing these assets twice over.

1.6.2 A Question of Standards

Like other utility services, water and wastewater are typically governed by national standards. For water quality, these are led by the World Health Organization's guidelines (WHO, 2011) which are then adopted at the national level, for example the Water Supply (Water Quality) Regulations, 2000 in England and Wales. In Europe, a series of direc-

tives also cover water and wastewater standards, including; Drinking Water (1998/83/EC), Bathing Water (1976/160/EEC and revised as 2007/7/EC), Urban Wastewater Treatment (1991/271/EEC) and the Water Framework (2000/60/EC).

Regardless of the power source, electricity will be delivered to a common standard across a utility and indeed a country. Likewise, telecommunications services depend on commonly agreed transmission protocols for both fixed-wire and mobile services. Both services are cheap to transmit over substantial distances between population centres in relation to the revenues these services generate.

In contrast, every water catchment area has its own characteristics. These include the amount of rainfall, its patterns and seasonality, the underlying rocks, geomorphology (the interaction between the landscape and its underlying strata), the presence of aquifers, land use and run-off, population density and distribution, the relation between renewable water resources and demand, and how water and wastewater is managed within the area.

Water is comparatively expensive to transport across catchment areas in relation to the value of the service. Where a utility uses water from a variety of sources, each source may need a specific treatment regimen before it can be released into the distribution network. Indeed, water from different sources will react differently when passed through the mains network (more acidic water will reach with iron pipes, causing corrosion and discolouration) and domestic networks (more acidic, or plumbosolvent water will dissolve lead pipes and solder, which may raise lead concentrations above the applicable standards).

1.6.3 Disruption in a Conservative Sector

A disruptive technology is one which changes the nature of its intended market. For example, railways, internal combustion engines and commercial flight have had a disruptive influence in the business of transportation, as have the telegraph and fixed-wire and mobile telephony in communications.

Despite its conservative nature, significant disruptive events have taken place in the water and sewage sectors. Examples of genuinely disruptive developments in water and wastewater services include the first slow sand filtration system for water for large scale water treatment which opened in Paisley, Scotland in 1804 (Huismann and Wood, 1974) and the development of the activated sludge sewage treatment by Edward Arden and William Locket in 1913–14 (Alleman, 2005).

More recently, reverse osmosis for desalination was developed by Sidney Loeb and Srivasa Sourirajan from the late 1950s and the first commercial reverse osmosis desalination at Coalinga, California entered service in 1965 (Loeb, 2006) and membrane technologies for wastewater treatment and water recovery were transformed by the development of the submerged membrane bioreactor in 1989 (Yamamoto et al., 1989).

Most current and anticipated smart water developments are set to offer incremental rather than disruptive improvements in efficiency and cost-effectiveness. It is the potential ability to integrate and to redouble these incremental benefits into a smart water system that is disruptive.

1.7 The Size of this Market; Estimates and Forecasts

How big is the market for smart water systems and products and how big might it become? A wide number of companies carry out research on the current and forecast

size of various technology markets. Data from surveys that are in the public domain (available through press releases, conference presentations or in openly available surveys) is presented in six tables below and placed in its context.

What counts as 'smart' varies from survey to survey as well as the actual amount of hardware involved. Because of the broad nature of definitions used for smart water between the companies surveying the sector there is an equally broad range of market estimates as well as forecasts. No survey is likely to be definitive and no one survey may be more accurate than another, but by comparing them, an overall impression can be made. Their value lies in showing how analysts following the sector perceive its current status and its potential growth and how this perception is changing over time.

The differences between market estimates over time also highlight the relatively early stage of this market's evolution and that it is a sector that is in rapid phase of development. Surveys will vary from year to year due to currency fluctuations against the US dollar as well as changing assumptions about future economic growth.

1.7.1 A Survey of Surveys

A total of 22 surveys and forecasts have been noted, eight covering the overall market (Table 1.1) and 14 looking at specific sub-sectors (Tables 1.2 to 1.6). A CAGR (compound annual growth rate) has been calculated where it was not initially available, to allow the comparison of growth projections. The Lux (2010) survey was one of the earlier ones notes and forecast growth rates are particularly high because of the small market base at the time of the survey.

It should be noted that the market estimates and forecasts provided by Marketsandmarkets are higher in their 2015 and 2016 surveys than in the 2013 survey. A lower CAGR forecast for 2016–21 than for 2015–20 reflects a higher initial market size.

The more recent surveys start from an appreciably higher market estimate base and generally point to a market that will be more substantial than previously anticipated.

Looking at their 2013 market estimates for sub-sectors, GWI (2014) splits the market into four main areas: network optimisation ($726 million), leakage management ($1,494 million), metering and customer services ($1,322 million) and water quality monitoring ($77 million).

Table 1.1 Smart water – overall surveys.

$ billion	Start year	End year	Start	End	CAGR
Lux (2010)	2009	2020	0.50	16.30	37.3%
IDC Energy Insights (2012)	2011	2016	1.40	3.30	18.7%
GWI (2014)	2013	2018	3.62	6.90	13.8%
Marketsandmarkets (2013)	2013	2018	5.43	12.03	17.2%
Transparency (2014)	2012	2019	4.81	15.23	17.9%
Marketsandmarkets (2015)	2015	2020	7.34	18.31	20.1%
Marketsandmarkets (2016a)	2016	2021	8.46	20.10	18.9%
Technavio (2016)	2015	2020	7.00	16.73	19.0%

Adapted from Transparency Market Research (2014); Minnihan (2010); Marketsandmarkets (2013, 2015, and 2016a); IDC (2012) and Global Water Intelligence (2014); Technavio (2016).

Table 1.2 Smart meters.

$ billion	Start year	End year	Start	End	CAGR
TechNavio (2008)	2008	2012	0.24	0.51	20.1%
Lux (2010)	2009	2020	0.21	6.30	36.0%
Pike Research (2011)	2010	2016	0.41	0.86	13.1%
IMS Research (2011)	2010	2016	0.55	0.95	9.5%
Frost+Sullivan (2014)	2013	2017	3.48	5.18	10.5%
IHS Tech (2014)	2013	2020	0.58	1.23	11.5%
Marketsandmarkets (2016b)	2015	2021	3.73	5.67	7.2%
Technavio (2017)	2016	2021	4.83	12.18	20.3%
Research and Markets (2017)	2015	2025	3.75	8.80	8.8%

Adapted from TechNavio (2008 and 2017); Minnihan (2010); Pike Research (2011); IMS Research (2011); Frost and Sullivan (2014); IHS Tech (2014); Marketsandmarkets (2016b) and Technavio (2017).

Table 1.3 Smart water networks.

$ billion	Start Year	End Year	Start	End	CAGR
Lux (2010)	2009	2020	0.16	3.30	31.5%
Navigant Research (2013)	2013	2022	1.12	3.30	12.8%
Frost+Sullivan (2012)	2010	2020	0.35	6.44	33.8%
Navigant Research (2016)	2016	2025	2.50	7.20	11.2%

Adapted from Minnihan (2010), Frost and Sullivan (2012) and Navigant Research (2013 and 2016).

Table 1.4 Leakage management.

$ billion	Start year	End year	Start	End	CAGR
GWI (2014)	2013	2018	1.49	2.80	13.3%

Adapted from Global Water Intelligence (2014).

Table 1.5 Water mapping.

$ billion	Start year	End year	Start	End	CAGR
Lux (2010)	2009	2020	0.02	3.20	56.6%

Adapted from Minnihan (2010).

While the Navigant 2016 CAGR is lower than the 2013 forecast, the anticipated market size is appreciably greater and indeed the 2016 market estimate is almost the size of the previous survey's 2020 forecast.

Table 1.6 Water quality monitoring.

$ billion	Start year	End year	Start	End	CAGR
Lux (2010)	2009	2020	0.11	1.10	23.4%
GWI (2013)	2013	2018	0.08	0.14	13.4%

Adapted from Minnihan (2010) and Global Water Intelligence (2014).

The water testing and analysis market remains dominated by traditional approaches. Marketsandmarkets (2015b) forecasts the overall market, including laboratory systems will be worth $3.5 billion in 2019, growing at 5.2% pa between 2014 and 2019.

According to Aquaspy (Aquaspy, 2013), $210 million was spent on smart irrigation in 2012; $100 million on water irrigation control systems, $30 million on monitoring, $10 million on 'fertigation' (combined fertilisation and drip irrigation systems) and $70 million on greenhouse control systems. Marketsandmarkets (2015c) estimates the overall soil moisture sensing market was worth $98 million in 2015. The smart irrigation market is analysed in greater detail in Chapter 7.

Another way of considering smart water in its broader context is to look at overall spending on smart systems and the hardware that is directly related to it such as metering and monitoring hardware. This was examined by GWI (2016) as 'digital water' with a market with $20 billion in 2014 and projected to grow to $30 billion pa by 2020. The market sizes for treatment and distribution and collection are seen as broadly equal in size.

The main areas of difference between 'digital' and 'smart' relate to those elements of testing, metering and sensing, which while part of smart networks, are not smart appliances in themselves. Parts of automation and control will also include non-smart elements. What these numbers highlight is the non-smart aspects of water hardware that enable smart systems to operate.

To put the smart water figures into their broader context, Marketsandmarkets (2015) estimates that the smart cities market (covering all urban services) was worth $411 billion in 2014 and will grow to $1,135 billion by 2019. GWI (GWM 2015, 2014) estimates that capital spending in 2013 on water infrastructure was $102 billion, rising to $131 billion by 2018 and $110 billion rising to $142 billion for wastewater over the same period.

1.8 Venture Capital Funding Flows

The information in this section is restricted to that which has been provided at conferences, in press releases and articles that are in the public domain. The awkward relationship between water and the rest of the Cleantech sector is highlighted in Venture Capital spending. For example, Boogar Lists is a USA based database of over 2,000 venture capital and Private Equity firms (Boogar Lists, 2014). It lists 89 Cleantech venture capital funds globally, but these do not include Apsara Capital (London) or XPV Capital (Toronto). These are the only dedicated water Cleantech venture capital funds known to be in operation during this period.

Table 1.7 outlines overall venture capital investment in the water sector between 2006 and 2013.

Table 1.7 Water Cleantech venture capital funding, 2006–13.

Water Cleantech	2006–07	2008–09	2010–11	2012–13	2014–15
Number of VC deals	56	159	204	257	139
VC funding ($ million)	293	915	936	1,023	587
Funding per deal ($ million)	5.2	5.8	4.6	4.0	4.2

Adapted from The Cleantech Group (2011) and i3 (2014, 2015 and 2017).

While there has been a decrease in the average deal size since 2009, the overall level of investment has been maintained. However, in 2016, there were 42 water VC investments, generating $173 million in funding. This is the lowest annual figure since 2006 with an average investment size of $4.1 million (i3, 2017).

Placing these figures, Table 1.8 outlines overall Cleantech venture capital investment and the relative size of water investment.

This indicates that the water sector has attracted a consistently small proportion of Cleantech venture capital funding to date.

1.8.1 Smart Water Cleantech Funding

According to the CleanTech Group (Neichin, 2011), in the five years from 2006 to 2010 'smart technology' accounted for 11% of total CleanTech venture capital funding ($3,910 million out of $35,210 million Cleantech funding overall) with 2% of this going on Smart Water ($80 million) compared with $1,600 million on Smart Grid, $686 million on Smart Buildings, $864 million on Smart Transportation and $680 million on Smart Industrial. This does not include indirect investment in smart water through smart grid and smart industrial companies.

1.8.2 Funding Smart Water Companies

With a significant number of smaller, privately owned companies driving much of the sector's development, venture capital is a particularly important element of the business of smart water.

Table 1.8 Cleantech and Water Cleantech venture capital funding, 2006–15.

Overall for Cleantech	2006–07	2008–09	2010–11	2012–13	2014–15
Number of VC deals	1,146	1,574	2,180	2,484	1,965
VC funding ($ billion)	11.4	16.9	20.4	15.9	18.8
Funding per deal ($ million)	10.0	10.7	9.4	6.4	9.6
Water as % of Cleantech funding	2.5%	5.4%	4.6%	6.4%	3.1%
Funding per deal ($ million)	5.2	5.8	4.6	4.0	4.2
Water deal size as % of Cleantech	52%	54%	49%	62%	44%

Adapted from The Cleantech Group (2011); The Cleantech Group (2013); The Cleantech Group (2014); Javier (2011); Haji (2012); Neichin (2011) and Cleantech Group (2016a).

Table 1.9 Evolution of smart water VC funding, 1998–2009.

Funding round	1998–01	2002–05	2006–09
A – Seed/early stage	73%	63%	37%
B – Development	27%	27%	31%
C – Commercialisation	0%	10%	17%
D – Expansion	0%	0%	15%

Adapted from Minnihan (2010).

1.8.3 The Evolution of Venture Capital Funding

Venture capital funding is based on a series of fund raisings, in effect, taking a company from its foundation based upon a potential product or service through to its eventually being listed or acquired. Table 1.9 summarises how funding of smart water companies has evolved over a 12-year period.

In a separate survey, in 2009, 70% of deals were for early stage investments (A and B in Table 1.9), while in 2010-13, the proportion varied between 46% and 55% (i3, 2014a). In 2016 (i3, 2017), 24% of water companies at the VC stage were pre-revenue (seed / early stage), 24% development (revenues of less than $500,000), 29% at commercialisation (revenues of $0.5-5.0 million) and 23% at the expansion stage (revenues above $5.0 million).

While there is an evident shift from early to later stage investment during this period, this change is not as straightforward as it may appear. Since the economic and financial sector turndown in 2008 venture capitalists have concentrated on development and expansion capital rather than seed and early stage capital, because while it offers the prospect of lower returns, it is also a lower risk investment.

Venture capital investors who are concerned about the conservative nature of the water sector do not appreciate the nature of the sector; 'in all industries…there is no such thing as a non-conservative customer' (David Henderson, comment at the World Water Tech Investment Summit, London, 29th February 2012).

Henderson also observed that there are enough companies looking for funding but the degree of entrepreneurial talent (the ability to commercialise and sell their offerings) in these companies is notably weak compared with their engineering capabilities. This means that more mentoring and support is needed than is usually the case. This is a concern as there are in the region of five venture capital funds worldwide which have four or more investments in water companies, as far as water Cleantech is concerned, the venture capital sector as a whole lacks the management support, market understanding and thematic commitment that is needed by these companies.

1.9 Two Perspectives on Venture Capital and New Technologies

As far as investors are concerned, water Cleantech investments have been characterised by a notably long period between the initial investment and the point when these

Table 1.10 Water companies in the Global Cleantech 100.

Number of entries in top 100	2010	2011	2012	2013	2014	2015	2017
All water companies	10	11	10	10	13	11	9
Smart water companies	3	2	2	1	3	2	2

Adapted from Cleantech Group, 2011, 2012, 2013, 2014, 2015, 2016b and 2017.

investments can be realised. It may be that this not so much the case when it comes to smart water Cleantech, but investor caution remains.

1.9.1 The Global Cleantech 100 – Cleantech Companies to Watch

Since 2010, The Cleantech Group has invited a panel of judges to select the top 100 emerging Cleantech companies (Table 1.10). It provides an annual snapshot into how these judges perceive innovation in the Cleantech sector to be developing. It also provides a snapshot as to their perception of water and smart water companies within this top 100.

Companies listed are involved in for smart irrigation (AquaSpy), smart metering (Fathom, three appearances), pressure management (i2O with three appearances), leakage management (Takadu, with six appearances) and water quality monitoring (Universtar).

This suggests that emerging water Cleantech companies are consistently more popular as prospects than as investment targets and that appears to be especially the case when considering smart water Cleantech companies.

1.9.2 The Gartner Hype Cycle – Investor and Customer Expectations and Realities

Gartner is a Stamford, CT based information technology consulting firm founded in 1979.

Through its experience in following for example the development of mobile communications in the 1980s and the Internet in the 1990s, Gartner has examined new technologies and their application are perceived by investors and customers. To this end, they developed the Hype Cycle, a tool for looking at the commercial evolution of an emerging technology. The Gartner Hype Cycle (Gartner, 2015a) consists of five stages. The interpretations in Table 1.11 are the author's.

Table 1.11 The Gartner Hype Cycle and smart water (1 = low to 5 = high).

	Trigger	Peak	Trough	Slope	Plateau
Risk	5	4	3	2	1
Opportunity	5	3	4	3	3
Funding need	1	2	4	5	3

Author's analysis, using the Gartner (2015a) framework.

1) Technology trigger (on the rise) – This where a prototype (potential new product) is announced, which has potential applications (proof of concept) but have not been tested in real-life conditions. The work is funded by personal investment or company funding, grants, angel investors, family office investment, and sometimes by early stage venture capital (first round of VC fund raising).
2) Peak of inflated expectations (at the peak) – pre-commercial trials of the prototype start, some of which may work, while others fail. This is accompanied by considerable media interest, looking at the possibilities for the technology. Initial contact with potential clients is made and external investment shifts towards family office funding early stage venture capital (first and second VC fund raising rounds).
3) Trough of disillusionment (into the trough) – Delays in product development and problems replicating lab bench performance in real-life conditions mean that the failure rate reaches its peak. Many projects are abandoned and those which continue need continued support from the company and further funding to develop applications that their potential clients need through pilot tests (first to third stage VC fund raising rounds).
4) Slope of enlightenment (climbing the slope) – Commercially viable applications are demonstrated through pilot tests and early adopter customers. Further product development widens the product's applicability and performance. Some products are acquired by incumbent companies, with funding coming from late stage venture capital (second to fourth VC funding rounds) and expansion capital.
5) Plateau of productivity (entering the plateau) – The product is increasingly seen as commercially and technically viable and is integrated into extant systems and applications. The emphasis shifts towards commercialisation, marketing and developing new versions and applications. The product is mainly funded by late stage venture capital (second to fourth VC funding rounds) and expansion capital with a trade sale to an incumbent player or a Stock Exchange Listing under consideration.

A tool such as the Hype Cycle allows companies and investors to consider how technologies are involved from the perspective of broad market acceptance, rather than that of enthusiasts such as early adopter utilities or early stage investors.

During 2015, Gartner published a series of updates (Gartner, 2015b, 2015c, 2015d, 2015e and 2015f) looking at the development of various technologies. In 2015, water management was seen as just entering the trough of disillusionment (stage 3), reaching the plateau in 2–5 years, having been noted at the peak of inflated expectations in 2012 (2–5 years to the plateau).

Other relevant areas seen at the peak (stage 2) in 2015 include; energy water nexus, smart city framework, sustainable performance management, the Internet of Things, meter data analytics and big data in energy and utilities. In contrast, geospatial imagery for utilities and geospatial platforms are at the technology trigger stage (stage 1). Other themes seen as going into the trough include advanced metering infrastructure, asset performance management and asset investment planning tools while climbing the slope to the plateau (stages 4 and 5) includes meter data management and environmental monitoring and control.

It is evident that with the exception of meter data management and environmental monitoring and control, most smart water applications are perceived as emerging technologies.

1.10 Sales of Smart Systems

The Gartner Hype Cycle (1.9.2) is a useful reminder that smart water is, and will be for some years, an emerging technology. Even so, significant commercial sales are being seen in a number of areas, as will be discussed later in this book. Smart water metering is the most obvious case, with utility wide rollouts seen for example in Malta, England (Southern Water), and the USA (Global Water).

The market estimates in section 1.7 indicate sales of smart water products in the region of $3.62–7.34 billion in 2013–15. The principal areas of activity, along with water meters, are smart networks, leakage management and smart irrigation. It is a market which is being primarily driven by early adopters, utilities, industrial water users and growers who stand to benefit the most from approaches that have yet to be fully commercially adopted.

1.11 Smart Water for Consumers

In terms of public perception, this is by some way the largest sector to date. Even so, the development of customer interfaces is at an early stage in terms of being easily used and manipulated and the main challenge there is to influence and inform customer behaviour over a significant period of time.

At present, the emphasis is on modifying consumer behaviour through helping them to minimise their water use. The next step is going to be in enabling them to notice internal leaks and in the timing of their water use to ease peak demand. Due to the amount of energy consumed when heating water, consumers can also be alerted to potential energy savings.

1.12 Smart Water for Utilities and Industrial Customers

A broad suite of applications are being used or are under development for municipal and industrial customers. Smart systems are either installed when replacing or upgrading extant systems (metering and monitoring for example) or as entirely new offerings. For example, smart meters are being installed by a number of utilities in the UK where customers previously did not have water meters. Smart approaches are being used to minimise the costs of providing services through optimising the efficiency of extant assets and by preventing the development of surplus assets through the more efficient use of extant assets and suitable demand management measures. A secondary attraction for many of these customers lies in the scope for integrating a number of incremental improvements. This means that interoperability between systems and common standards are a particular concern.

Utilities currently using smart water approaches include Hera-Modena (Modena in Italy, remote reading systems for real-time smart water meters and other urban utility services), Haghion (Jerusalem in Israel, real-time network monitoring for early leakage detection), Wessex Water (UK, trials for smart sewer metering), Aguas de Cascais (Portugal, integrated

non-revenue water reduction), South East Water (UK, mains water pressure monitoring and management), Northumbrian Water (UK, integrated data access and control at the regional level), and Vitens (Netherlands, remote and real-time water quality monitoring).

1.13 Irrigation and Surface Water Monitoring

Software systems for the remote monitoring of soil moisture enable water and nutrients to be introduced in the most effective manner, improving yield as well as lowering water consumption. Smart irrigation systems can also optimise the effective delivery of water and nutrients. These also apply for urban landscape irrigation software to minimise park, playing field and garden watering, in turn lowering water use, nutrient run-off and erosion. These will be discussed in more detail in Chapter 7.

Smart water is also being used in reservoir and dam management, and monitoring of surface water quality and inland water flows and modelling and monitoring flood vulnerability. Increasing rainfall variability as a result of climate change is a particular driver behind the need for more rapid monitoring of surface water quality and flow and the ability to predict flood and drought events as far ahead as possible.

1.14 Water and the 'Internet of Things'

The Internet of Things refers to the interconnection of monitoring systems into what is seen as an all-encompassing whole and therefore it is a somewhat poetic expression for imagining a world which is limitlessly and universally interconnected via the Internet. It comes in part from the idea of 'big data' that the analytical power of information increases as more data from more sources is integrated. The 'IoT' expression was coined by Kevin Ashton in 1999 (Ashton, 2009). It functions via device to device communications where each device can be identified within a network so as to provide a coherent and comprehensive coverage of the data sought. A particular area of interest is in integrated monitoring and management of domestic appliances.

For the water sector, the Internet of Things is an extension of the smart water concept to include other applicable and related services, thereby linking water with other utilities and water consuming devices. The Internet of Things has the potential to alter popular expectations about utility services, water consumers, and how these affect other areas. For example, bathing water quality data in real-time becomes a consumer tool while the role of irrigation agriculture can be transformed when it enables optimal water and nutrient inputs to be deployed.

1.15 Some Initial Caveats

Chapter 9 will discuss in some detail some of the broader challenges facing smart water. The two points considered here deserve an immediate mention because they will recur through the rest of this book.

1.15.1 A Caveat about a Swiftly Evolving Future

This survey is focussed on technologies and techniques which are either in development or have only recently been deployed. It is therefore biased towards possibilities rather than potential pitfalls. We only have forecasts for the scale and speed of the deployment of these new approaches.

Customer behaviour is often overlooked by utilities. Likewise, the deployment of a large array of low cost, Internet-linked domestic devices as part of the Internet of Things carries the risk that their system security and integrity will be lower than for more expensive appliances and applications. They may become a 'back door' for accessing customer information or interfering with operations.

Smart water systems are constantly emerging and evolving. For example, during the UK floods in December 2015 to January 2016, drones were used to gather data about river flows and flood plain inundation at pressure points down river systems, covering 60 km of river bank in a day (Kinver, 2016). This allowed for the first time an insight into how flood plains were in fact holding water during the floods.

1.15.2 A Caveat on Data and the Silo Mentality

Unless concentrating on a deliberately small set of criteria, it is essential to ensure that all possible data sources can be accessed and usefully integrated. Gillian Tett's book 'The Silo Effect' (Tett, 2015) contains a telling anecdote about how open data allowed New York City to deal with yellow (catering) fat in its sewers. New York's government has been traditionally run on compartmentalised lines and communications between its various activities has been an impediment in addressing chronic problems affecting the city such as fire risk and fraud. In 2011, a team was recruited with a remit to use all of the city's data sources to address such problems. To identify where the fat was being generated and discharged, they looked at sewer blockage incidents and related them to tax returns, business licences and kitchen fires. From this, they identified the most effective data came from listing kitchens which had not applied for the appropriate waste disposal licence. Instead of threatening these businesses with prosecutions, the team presented the database to the health and safety and fire inspection departments and another department that was seeking to promote biofuel recycling. When the caterers were advised that they were throwing a valuable resource away, compliance became commonplace.

There is a danger of extrapolating too much from limited information when considering an emergent application such as smart water. Chapter 9 will consider at some length all the caveats and concerns that have been identified to date.

Conclusions

Smart water is an emerging subset in Cleantech and smart Cleantech in particular. In contrast with the rest of the Cleantech sector, it involves serving a notably conservative and risk-adverse business and one which faces continuing funding shortages.

The challenge for smart approaches is to assist clients in delivering more and better services at a lower cost than before by enabling them to adopt more radical approaches than they would hitherto have countenanced. For the water sector, this also means

improved higher degrees of public health and environmental compliance at a swifter pace than traditionally seen.

As industrial clients do not face the same set of constraints as utilities, but share the same needs to improve the water-related efficiency of their processes, they can serve as a platform for commercialising innovative approaches.

The conservative nature of the water sector means that the technology which will be widely adopted in 2035 is already here (Sedlack, 2016) as water technology typically takes 20 years to move from conceptual development to broad adoption (Parker, 2011). The Gartner Hype Cycles suggest shorter gestation periods, based on experiences in less conservative sectors. It may be that one of the distinguishing features of smart water will be a more rapid adoption process than the sector normally experiences. Nevertheless, the basic elements of a broad variety of smart water approaches are already being developed and applied at the commercial level. While the essentials may remain relatively unchanged, quite a lot may happen in the way that smart water approaches are developed, adapted and adopted.

In commercial terms, smart water appears to be a small market. That would be misleading as much of smart water's potential lies in being a tool for improving the effective deployment of other assets and avoiding the need to invest as much in new assets as originally planned.

To some extent, smart water and water and the Internet of Things are more of a philosophy than a single concept (Reynolds, L. personal communication, August 2016). Both have been enabled by the emergence of technological innovation and user-centred applications and their application across the business of water services. It will become evident that smart domestic applications (especially those using the Internet of Things) are quite separate from smart approaches designed to optimise water and wastewater network efficiency and that smart irrigation is quite distinct from both of these. What unites them is their potential to use water and wastewater more efficiently while lowering the cost of their delivery and treatment and enabling operators and consumers to be fully informed about the impact of their water usage and to appreciate how their behaviour can be modified towards more sustainable consumption patterns.

These smart water approaches have three chief elements in common; the potential to use water and wastewater more efficiently, lowering the cost of their delivery and treatment and informing operators and consumers. Informed operators and consumers appreciate the cost and impact of their water usage and consider how their behaviour can be modified towards more sustainable consumption patterns.

References

Alleman J E (2005) The Genesis and Evolution of Activate Sludge Technology, http://www.elmhurst.org/DocumentView.aspx?DID=301 accessed 20th May 2011.

Anderson R and Fuloria S (2010) On the security economics of electricity metering. Paper presented to the 9th Workshop on the Economics of Information Security (WEIS 2010), Harvard University, USA, June 8th 2010.

Aquaspy (2013) Presentation to the World Water Tech Investment Summit, London 6–7 March 2013.

Ashton (2009) That 'Internet of Things' thing. RFiD Journal, 22nd June 2009. http://www.rfidjournal.com/articles/view?4986.
Boogar Lists (2014) http://www.boogar.com/resources/venturecapital/clean_tech2.htm.
Cleantech Group (2011) Global Cleantech 100 2010. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2012) Global Cleantech 100 2011. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2013) Global Cleantech 100 2012. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2014) Global Cleantech 100 2013. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2015) Global Cleantech 100 2014. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2016a) Global Cleantech 100 2015. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2016b) Q4 FY/2015 Innovation Monitor. Cleantech Group LLC, San Jose, USA.
Cleantech Group (2017) Global Cleantech 100 2016. Cleantech Group LLC, San Jose, USA.
Drago C M (2009) The Smart Grids in Italy - an example of successful implementation. Presentation by IBM to the Polish Parliament, October 27th 2009. http://www.piio.pl/dok/20091027_The_Smart_Grids_in_Italy_-_an_example_of_successful_implementation.pdf.
European Union (2009) Directive 2009/72/EC concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. Official Journal of the European Union, August 14th 2009, L 211/55–93.
Forer G and Staub C (2013) The US water sector on the verge of transformation. Global Cleantech Centre white paper. EY, New York, USA.
Frost and Sullivan (2012) Global Smart water grids to see increasing investment over the next decade. Presentation to the World Water Tech Investment Summit, London, 29th February 2012.
Gartner (2015a) Hype Cycle Methodology. http://www.gartner.com/technology/research/methodologies/hype-cycle.jsp.
Gartner (2015b) Gartner Hype Cycle for Utility Industry IT, 2015. https://www.gartner.com/doc/3096022?ref=ddisp.
Gartner (2015c) Hype Cycle for Smart Grid Technologies, 2015. https://www.gartner.com/doc/3092617?ref=ddisp.
Gartner (2015d) Hype Cycle for Green IT, 2015. https://www.gartner.com/doc/3101522?ref=ddisp.
Gartner (2015e) Hype Cycle for Sustainability, 2015. https://www.gartner.com/doc/3101519?ref=ddisp.
Gartner (2015f) Hype Cycle for the Internet of Things, 2015. https://www.gartner.com/doc/3098434?ref=ddisp.
Global Water Intelligence (2014) Market Profile: Smart water networks. Global Water Intelligence, January 2014, pages 39–41.
Global Water Intelligence (2016) Digital transformations set to boost buoyant smart water market. Global Water Intelligence, October 2014, pages 35–37.
Gohring N (2008) Microsoft to discontinue MSN Direct. PC World, October 28, 2008. http://www.pcworld.com/article/174581/article.html.
Gómez-Expósito (2012) Smart Grids: so old, so new. Mondragón, December 19, 2012.
GWM 2015 (2014) Global Water Markets 2015, Media Analytics Limited, Oxford, UK.
GWI (2016) Water's Digital Future: The outlook for monitoring, control and data management systems. Global Water Intelligence, Oxford, UK.

Haji S (2012) Quoted in Water Acquisitions Rise: Will Venture Capital Follow? Forbes 28th February 2012.
Heath J (2015) Smart Networks. Presentation to Smart Water: The time of now! SWAN Forum Conference, London April 29–30th 2015.
Henderson D (2012) Comment at the World Water Tech Investment Summit, London, 29th February 2012.
Huismann L and Wood E (1974) Slow sand filtration. World Health Organization, Geneva, Switzerland.
i3 (2014a) i3 Quarterly Innovation Monitor: Water and Wastewater 4Q 2013. Cleantech Group LLP. Page 2.
i3 (2014b) i3 Quarterly Innovation Monitor: Water and Wastewater 3Q 2014. Cleantech Group LLP. Page 1.
i3 (2014c) i3 Quarterly Innovation Monitor: Water and Wastewater 4Q 2013. Cleantech Group LLP. Page 1.
i3 (2014d) i3 Quarterly Innovation Monitor: Water and Wastewater 4Q 2013. Cleantech Group LLP. Page 2.
i3 (2015) i3 Quarterly Innovation Monitor: Water and Wastewater 4Q 2014. Cleantech Group LLP. Page 2.
i3 (2017) https://i3connect.com/tags/water-wastewater/1181/activity.
IDC Energy Insights (2012) smart water spending forecast: 2012. IDC, Milan, Italy.
IHS Technology (2014) Water Meters Report – 2014. Smart Water Meters Intelligence Service. IHS Markit, London, UK.
IMS Research (2011) The World Market for Water Meters – 2011. IMS Research, Wellingborough, UK.
IMS Research (2013) Smart Water Management Market by Solutions (Network Monitoring, Pressure Management, Analytics, Meter Data Management), by Services (Valve and Information Management, Pipeline Assessment), by Smart Meter Types, by Region – Global Forecast to 2020. IMS Research, Wellingborough, UK.
Javier M (2011) Ontario Global water Leadership Takeaways, Cleantech Group 2011.
Kinver M (2016) UK floods: Drone provides researchers with unique data. BBC, 20-1-2016, http://www.bbc.co.uk/news/science-environment-35353869.
Loeb S (2006) Personal notes on the development of the Cellulose Acetate Membrane, prepared by and delivered by Sid Loeb at an honour ceremony of the first Inaugural Sydney Loeb Award by the European Desalination Association.
Marketsandmarkets (2013) Smart Water Management Market – Smart Water Meters, EAM, Smart Water Networks, Analytics, Advanced Pressure Management, MDM, SCADA, Smart Irrigation Management, Services – Worldwide Market Forecasts and Analysis (2013–2018).
Marketsandmarkets (2015a) Smart Cities Market by Smart Home, intelligent Building Automation, Energy Management, Smart Healthcare, Smart Education, Smart Water, Smart Transportation, Smart Security, and by Services – Worldwide Market Forecasts and Analysis (2014–2019).
Marketsandmarkets (2015b) Water Testing and Analysis Market by Product (TOC, PH, DO, Conductivity, Turbidity), Product Type (Portable, Handheld, Benchtop), Application (Laboratory, Industrial, Environmental, Government) and Region – Global Trends and Forecast to 2019.

Marketsandmarkets (2015c) Soil Moisture Sensor Market by Type (Volumetric and Water Potential), Application (Agriculture, Residential, Landscaping, Sports Turf, Weather Forecasting, Forestry, Research Studies and Construction), and Geography – Global Trends and Forecast to 2020

Marketsandmarkets (2016a) Smart Water Management Market by Advanced Water Meters (Meter Type and Meter Read Technology), Solution (Network Monitoring, Advanced Pressure Management, SCADA System, Advanced Analytics, Residential Water Efficiency), Service – Global Forecast to 2021

Marketsandmarkets (2016b) Smart Water Metering Market by Type, by Component, by Application and by Region – Global Trends and Forecast to 2021.

Michael W (2011) Insight of the week: Smart water investment just a drop in the bucket. Cleantech Insights blog, 28th January 2011, Cleantech Group LLP.

Micro Irrigation System Trends and Global Forecasts (2011–2016) Markets and Markets, March 2012, FB 1772.

Microsoft (2002) Microsoft Launches Smart Personal Object Technology Initiative. http://news.microsoft.com/2002/11/17/microsoft-launches-smart-personal-object-technology-initiative/

Minnihan S (2010) Water IT: How the $16 billion market will take shape. Lux Research. Presentation, 21 September 2010.

Navigant Research (2013) Smart Water Networks. Smart Water Meters, Communications Infrastructure, Network Monitoring and Automation Technologies, and Data Management and Analytics: Market Analysis and Forecasts. Navigant Consulting Inc.

Navigant Research (2016) Smart Water Networks. Water Meters, Communications Infrastructure, and Data Analytics for Water Distribution Networks: Global Market Analysis and Forecasts Navigant Consulting Inc.

Neichin G (2011) The State of Smart Water: Context, Capital and Competition. Presentation by the Cleantech Group to the SWAN Conference, London, 17th May 2011.

Northeast Group, (2015) Global Smart Water Infrastructure: Market Forecast (2015–2025) October 2015.

OECD (2012) Policies to support smart water systems. Lessons learnt from countries experience. ENV/EPOC/WPBWE(2012)6. OECD, Paris, France.

Parker D S (2011) Introduction of New Process Technology into the Wastewater Treatment Sector. Water Environment Research 83: 483–97.

Peleg A (2015) Water Networks 2.0: The Power of Big (Wet) Data. Presentation to Smart Water: The time of now! SWAN Forum Conference, London April 29–30th 2015.

Pike Research (2011) Smart Water Meters: Global Outlook for Utility AMI and AMR Deployments: Market Analysis, Case Studies, and Forecasts.

Research and Markets (2017) Global Smart Water Metering Market Analysis and Trends – Industry Forecast to 2025. Research and Markets, Dublin, Ireland.

Royan F (2014) Global Smart Water Metering Market. Presentation to SMi Smart Water Systems Conference, London April 28–29th 2014.

Sedlack D L (2016) The Limits of the Water Technology Revolution. Presentation to the NUS Water Megatrends Workshop, 25th February 2016, NUS, Singapore.

Shannon C E and Weaver W (1949) The Mathematical Theory of Information. University of Illinois Press, Urbana, USA.

Smart Grid Forum (2014) Smart Grid Vision and Routemap. Department of Energy and Climate Change and Ofgem, London, UK.

Technavio (2008) Global Smart Water Meters Market 2008–2012 forecasts the size of the global smart water meters market over the period 2008–2012. Technavio, London, UK.
Technavio (2017a) 2016–2020 Global Smart Water Management Report. Technavio, London, UK.
Technavio (2017b) Global Smart Water Meter Market, 2017–2021. Technavio, London, UK.
Tett G. (2015) The Silo Effect. Simon and Schuster, London, UK.
The Cleantech Group (2011) Investment Monitor Report.
The Cleantech Group (2013), Press Release, 3rd January 2013.
The Cleantech Group (2014), Press Release, 8th January 2014.
Transparency Market Research (2014) Smart Water Management Market (Component Types – Hardware, Solutions, Services; Meter Read Technology – Fixed network, Cellular network) – Global Industry Analysis, Size, Share, Growth, Trends, and Forecast 2013–2019.
Water Cleantech VC investment in the USA fell from $123 million in 2007 to $67 million in 2009, and recovered to $95-125 million pa in 2010–12.
World Health Organization (2011) Guidelines for Drinking-water Quality, Fourth Edition, WHO, Geneva, Switzerland.
Yamamoto K, Hiasa H, Talat M and Matsuo T (1989) Direct solid liquid separation using hollow fiber membranes in activated sludge aeration tank. Water Science and Technology 21: 43–54.