Emerging topics and technology roadmap for Information and Communication Technologies for Water Management

Executive Summary

Expected technology improvements in ICT for Water Management are to be done in the following steps:

- Development of technology for near-real-time measurements in water distribution networks. This will allow a better monitoring and modelling of network behaviour and will improve the management strategies. An increased number of sensors per user conducting real-time measurements of water consumption and monitoring user behaviour are to be considered.

- Development of technology to process large amount of data, it efficient and secure storage, data processing and sharing. This should also include data validation, reconstruction and aggregation algorithms as well as unified and standardised metadata description and sharing in accordance with Open Research Data and GEOSS Data Sharing principles.

- Development of technology to monitor water-energy nexus with main focus on reduction of energy consumption related to water processing. The approaches taken should ensure synergy by addressing both energy and water consumption. To achieve this, work should concentrate on ensuring near real-time metering of WDN and real-time metering of users as well as collection of contextual information.

1. Approach taken

This document was created based on the guidelines for H2020 call "Climate action, environment, resource efficiency and raw materials, Water innovation: Boosting its value for Europe", previous roadmap of ICT for Water Management created in 2013 and cluster meeting of 10 currently running projects that took place in February 2014 in Brussels. Based on this input and discussion with project representatives we identified target groups (actors) that will benefit from the use of ICT for Water Management systems, the most important aims and tasks to be addressed, essential emerging issues and gaps that need to be filled. Analysis allowed to create a list of emerging topics, technological challenges and define technology roadmap for ICT for Water Management in forthcoming "Water innovation: Boosting its value for Europe" calls.

2. Identified actors, challenges, issues and gaps

Target groups (actors) that ICT for Water Management projects should address include both water entities, citizens (end-users), business and individual customers as well as country, region and city governments. Out of this list water entities, end-users and governments are of the most interest for future calls and ICT related projects.

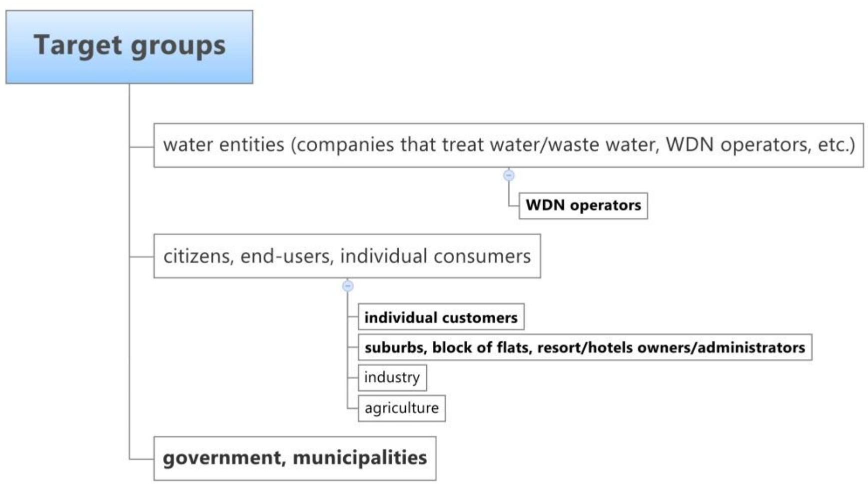

Fig. 1 Target groups for ICT for Water Management projects

Participants of the cluster meeting identified number of expected impacts and aims some of which are based on H2020 documents and the previous roadmap but others emerged during realisation and from observation of currently running projects. As agreed the expected impact of ICT for Water Management should be focused on three general technological areas identified by H2020 documents:

- significant reduction of water consumption,
- more than 50% reduction of energy demand related to water processing, and
- deployment of advanced ICT solutions for water management.

These areas are supported by aspiration to ensure interoperability between various systems, integration of various sources of information (e.g. geographic information system (GIS), weather forecast, etc.) and increased data sharing. These aspects were emphasized by all cluster meeting participants.

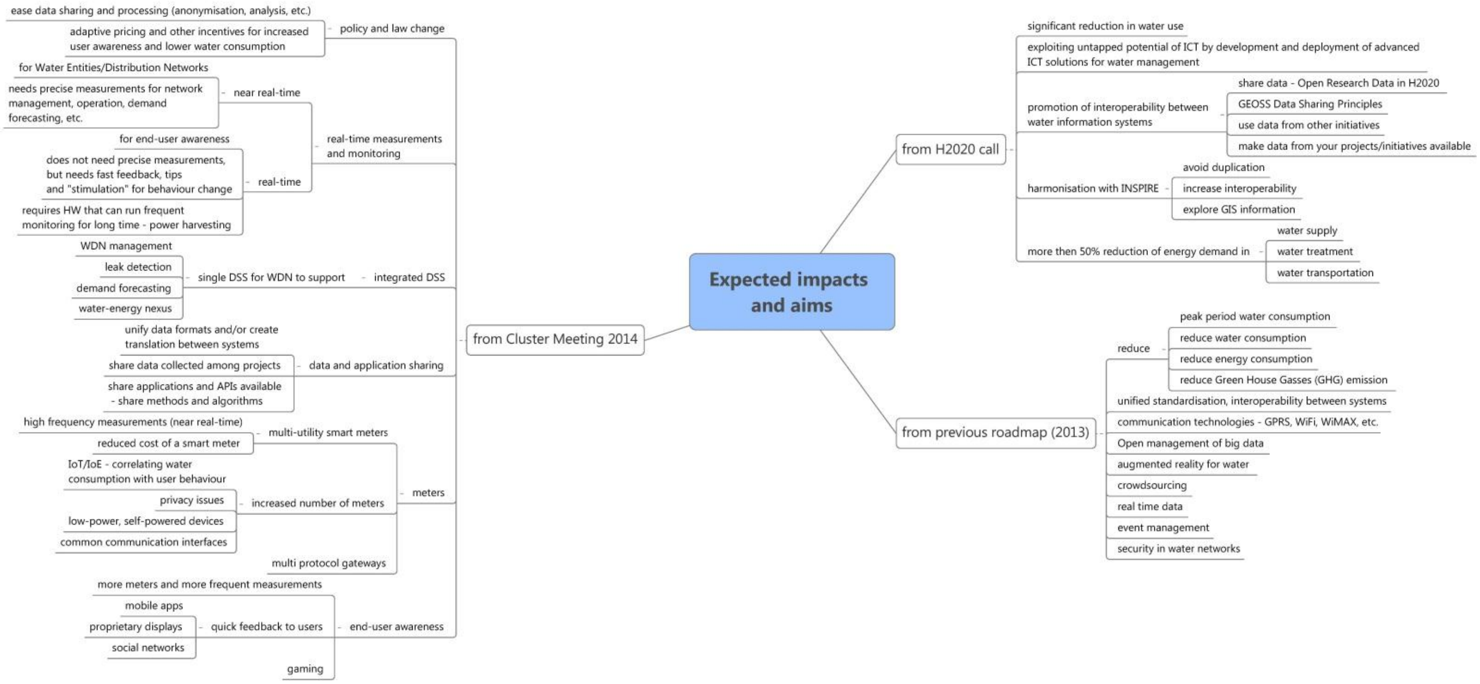

Fig. 2 The most important expected impacts and aims as identified by H2020 documents, previous roadmap and cluster meeting

General areas defined by H2020 documents capture most of the expected impacts and aims that have been presented in a more detailed way in the previous roadmap and during 2014 cluster meeting. In addition to those impacts and aims cluster meeting members pointed out the requirement for policy and law changes that are required in order to implement some of the envisaged functionalities (e.g. adaptive pricing) as well as simplify access to data collected by water entities. As a result cluster meeting participants defined expected impacts in larger detail and identified emerging issues that need to be resolved (Fig. 2).

Issues identified during the cluster meeting can be organised into three main groups. The largest group includes **technological issues** (Fig. 3) that address both software and hardware related issues. Among software issues participants of the cluster meeting emphasised the interoperability of systems, software development supporting harmonisation and reuse of software and data, processing algorithms and storage technologies that are capable to accommodate increasing amounts of data. Amid hardware issues attention was paid to the increasing number of various sensors that collect real-time and near real-time information (also contextual information), are battery powered and need to operate for a long time (at least several years), as well as technological improvements required for efficient processing of water and waste water, reuse and cascade use of water. Second group deals with **social issues** (Fig. 4) that result from the aspiration to increase user awareness and influence user behaviour. Project representatives pointed out that addressing these challenges requires involvement of experts in sociology, psychology and human behaviour. Some of the approaches discussed during the cluster meeting require solutions to **organisational issues** (Fig. 4) that constitute the third group. This group addresses security and privacy aspects of large and detailed data sets (including contextual and detailed information on end-user behaviour), policy and law changes required to implement incentives, adaptive pricing and safe reuse or cascade use of water.

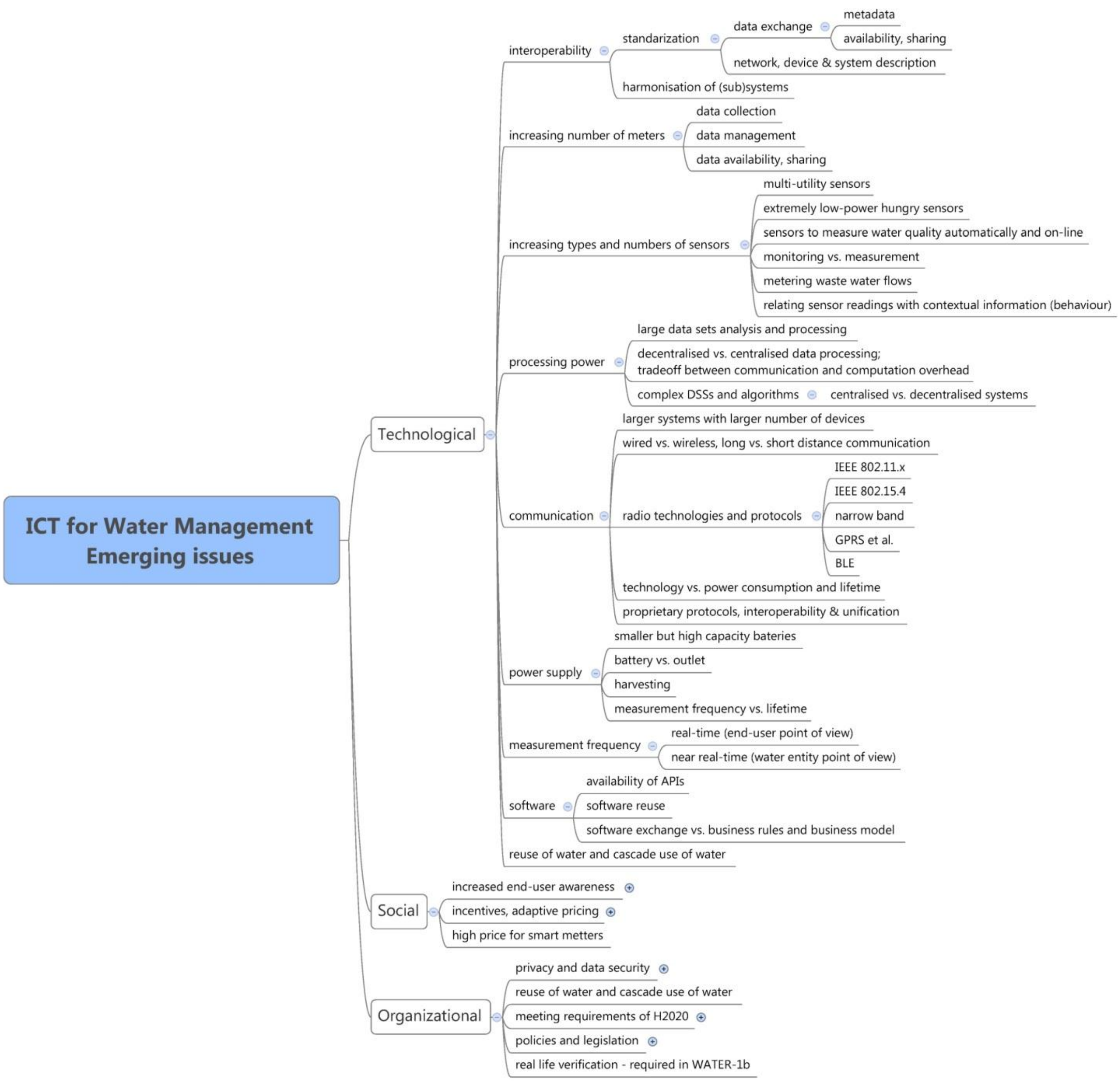

Fig. 3 Emerging technological issues in ICT for Water Management

Based on the available information and experience from on-going projects cluster meeting participants **identified gaps** (Fig. 5) that should be filled by current and future research projects. Most of the main eight gaps identified are correlated with each other, therefore, future initiatives should focus on expected impacts and address all of the related gaps. For example reduction in water consumption requires change in user awareness and improved water metering but also depends on the quality of decision support systems used for network monitoring and management (e.g. leak detection and management). Similarly the collection of large amounts of contextual information and integration with IoT/IoE poses challenges to efficient data collection, transmission, processing and sharing. It also raises privacy concerns regarding data security and end-user anonymity. Last but not least, efficient decision support system (DSS) requires efficient data sharing and data reuse mechanisms that are only possible if data unification and/or standardisation is ensured. Consequently it is important to stress that identified gaps should not be addressed separately but from the angle of the expected impact.

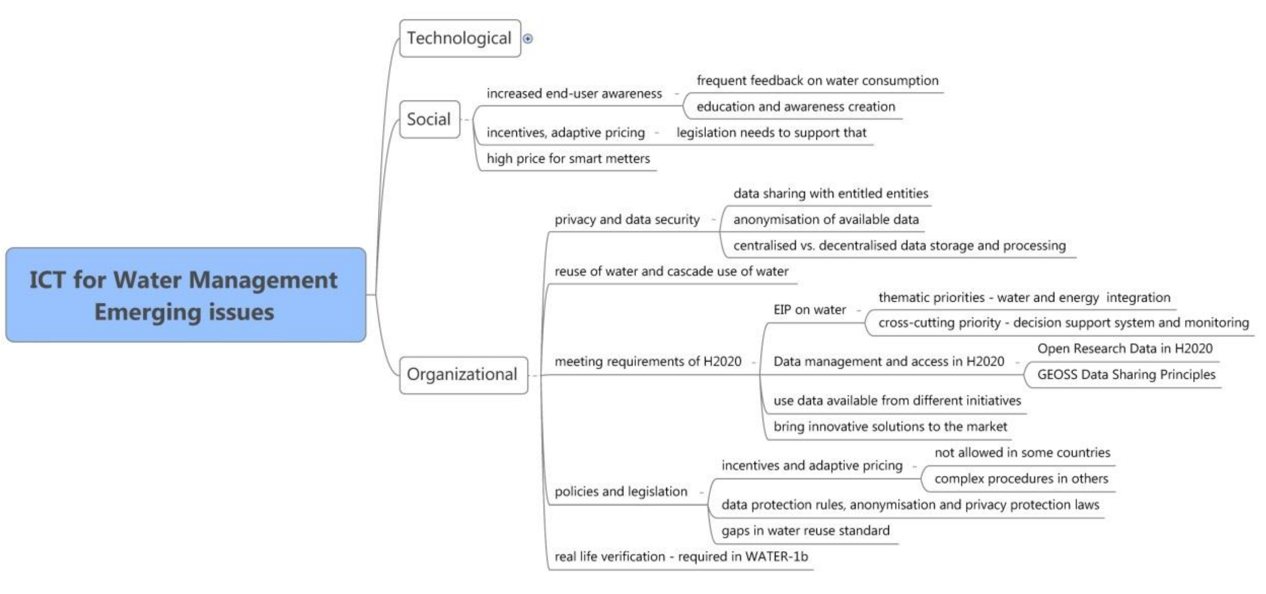

Fig. 4 Emerging social and organizational issues in ICT for Water Management

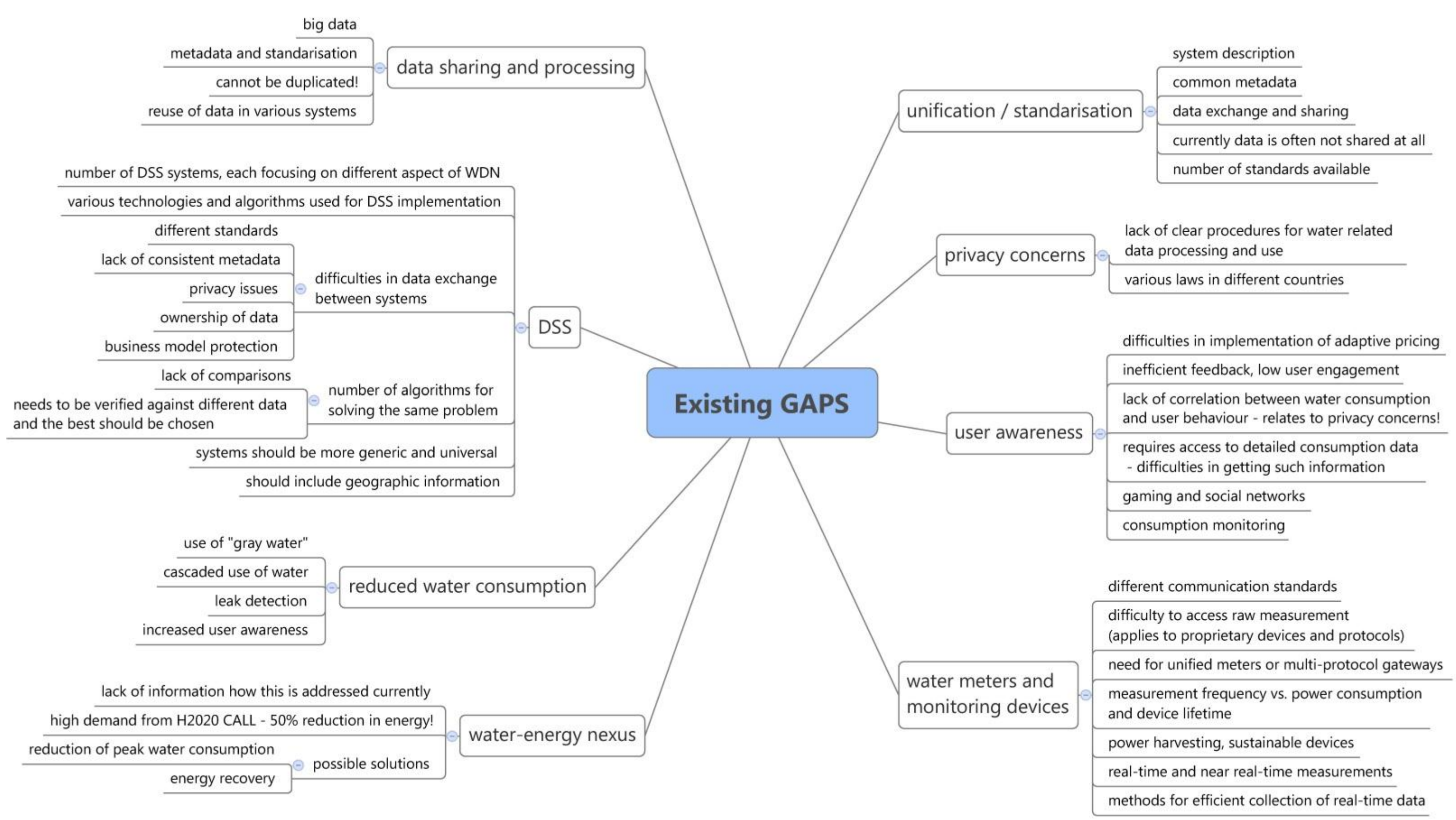

Fig. 5 Identified gaps in ICT for Water Management

3. Emerging topics

Based on round-table discussion with representatives of 10 research projects that are currently running in the area of ICT for Water Management as well as on strategic priorities for research and innovation in Horizon 2020 experts identified two main priorities within the area that research projects should focus on. These are:

- reduction of water consumption.
- reduction of energy consumed in relation to water processing.

Reduction of water consumption is a very broad priority that includes reduction of water consumed by end-users as well as improved management of the water distribution network in order to reduce non-revenue water and leakages, and optimise energy required to keep the network running. Within this priority four emerging topics were identified (Fig. 6) that are expected to significantly reduce amount of consumed water:

- user awareness and behaviour,
- reuse of water and cascade use of water,
- reduction of leakages,
- water distribution network monitoring and management.

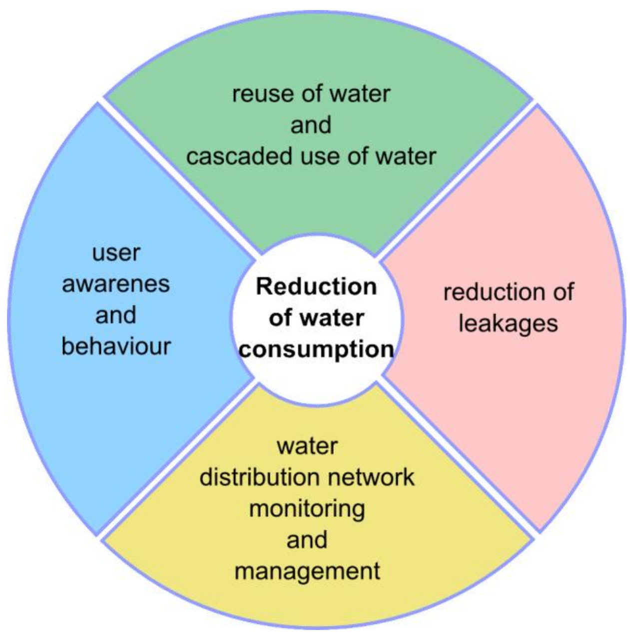

Fig. 6 Emerging topics in “Reduction of water consumption” priority

By now water entities, governments and municipalities are well aware of the need to reduce water consumption. However, **end-users awareness** is still small and unsatisfactory as it is usually only driven by water prices. As a result there is a need to increase user awareness on water scarcity and how it can be used more efficiently, in a more sustainable way in everyday life. Increased awareness has the potential to convince end-users to **change behaviour** and to consume water in a way that will help to protect natural resources. To achieve this goal end-users need to be provided with easy to understand and assimilate knowledge on issues related to availability, withdrawal, treatment, distribution and waste water treatment. End-users also need to be exposed to on-line, real-time information on their own water consumption, water footprint and information on how they can improve. Change in behaviour can be also encouraged by involving users in gaming and social networks targeting water issues. Additionally, incentives and adaptive pricing may stimulate desired behaviours.

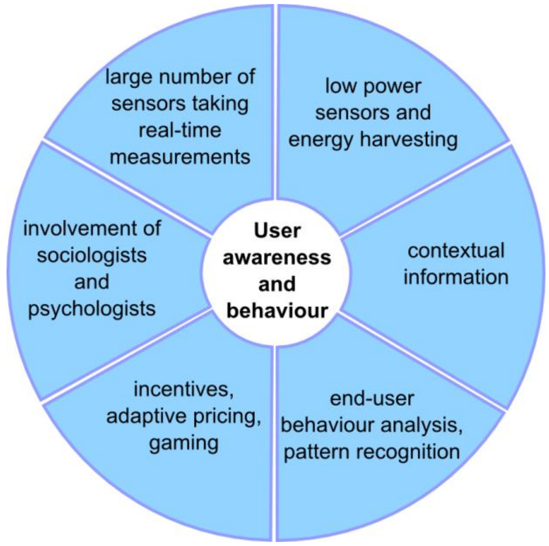

Fig. 7 ICT and non-ICT challenges for increased user awareness and change of behaviour

Change in user awareness and behaviour requires a number of improvements in ICT and non-ICT challenges, six of which are the most significant (Fig. 7). One of the most important challenges that is often underestimated addresses **involvement of sociologists and psychologists** in the development of systems that are intended to stimulate change in user behaviour. Such systems not only need to have nice looking and attractive user interfaces and functionalities but must convey and instil desirable ideas and patterns that users should adopt and follow. To affect consciousness and stimulate change in behaviour end-users need to be presented in real-time with information of their current water consumption and actions they can take in order to improve. This creates a technological challenge in **increasing number of sensors, taking real-time measurements** and correlating this information with **contextual information** on user actions, behaviour, weather conditions, etc. Sensors need to measure water consumed by every device drawing water (sinks, bath tubs, showers, washing machines, refrigerators, toilets, etc.) which implies low-cost solutions, that communicate wirelessly, can report consumption in real time and can operate for 5-10 years reliably requiring no maintenance. As a result water meter technologies need to be improved in order to provide meters with **low power consumption that can harvest electrical energy** and operate for a long time. An increased number of sensors together with contextual information will allow to conduct **end-user behaviour analysis, detect behavioural patterns** and constantly update methodologies used to stimulate end-user change. One possible approach to stimulate change of behaviour, that has already shown promising results, is to give **incentives to end-users**. This can be either achieved through water-related **gaming and social networks** or **adaptive pricing** which, in the simplest approach, may promote lower water consumption, but can be also used in order to reduce peak water consumption and related costs (of energy, of water distribution system maintenance that needs to accommodate variable operation conditions, etc.)

Concepts of **water reuse and cascaded use of water** (Fig. 8) have been already thoroughly analysed and well-understood, however, they are much less popular among end-users and systems based on such ideas are still far from being widely adopted. The most important challenge within this topic addresses the need for **development of devices** that can efficiently support reuse and cascaded use of water. Such devices are already developed and used around the globe (e.g. in Australia and US) but are usually limited to systems that use grey-water for plant watering. Reuse and cascade use of water also requires **change in end-user awareness** who need to be convinced that reuse and cascaded use does not pose health threats.

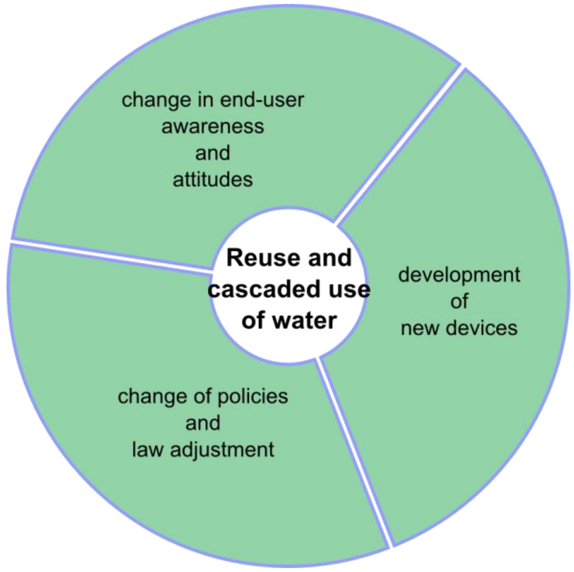

Fig. 8 ICT challenges that need to be addressed within water reuse and cascaded use of water topic

Another way leading to reduced water consumption is through improved **water distribution network monitoring and management**. The aim of water management systems is to operate water distribution networks (WDNs) taking into account broad perspective of various parameters: variable availability of water resources, changing demands, current state of the distribution network as well as aspects of energy consumption required. Six main challenges are identified for this topic (Fig. 9).

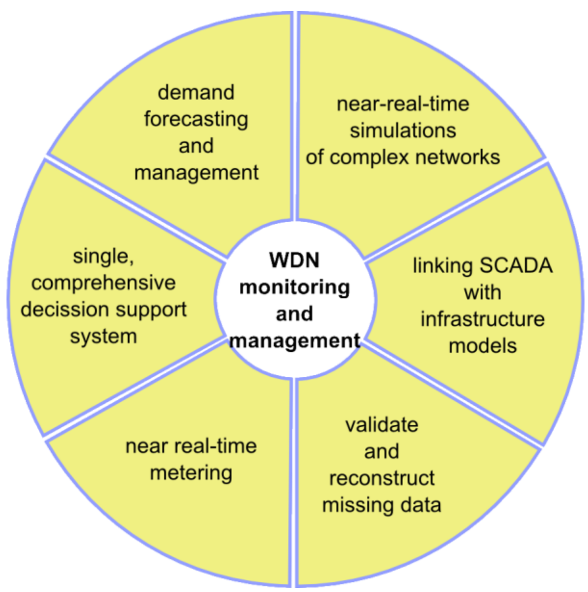

Fig. 9 ICT challenges required to be addressed within WDN monitoring and management topic

Current ICT systems used for monitoring and management of WDNs are fragmented and trimmed to accurately support specific aspects of WDN's operation. Consequently, water entities are required to use a number of different systems that often lack compatibility and cannot exchange information seamlessly. This often leads to situations where different systems base their operation on different, disjointed sets of information or require the same information to be collected multiple times. Therefore there is a real need for the development of a **single, comprehensive decision support system**, that will be able to accommodate a wide spectrum of WDN's issues and support water entities in efficient management of water network. Moreover, the DSS should be technology agnostic and sufficiently open to ensure interoperability with other systems, seamless exchange of data and possible future improvements. Taking into account that data may be missing DSSs must be able to **validate and reconstruct missing data** in order to ensure data correctness before it is processed and used for decision support. This implies that DSSs need to implement measures to ensure missing data can be reconstructed based on other measurements, historical data and other related information.

By now DSSs used by water entities are fairly efficient in management of water distribution network and available resources, however, there is a large area to be addressed in **demand forecasting and demand management**. These two challenges can help to save on energy bills, allow to prepare for changes in water availability and to influence and control the demand, e.g. leading to more balanced, sustainable water consumption and reduced peak energy consumption. Demand forecasting can also support water entities in forecasting future consumption and help to optimise water distribution systems accordingly. Apart from algorithms demand forecasting requires **near-real-time metering** of water distribution network that will allow to determine water consumption and water parameters, identify patterns and variances. Demand management is clearly linked with challenges from "User awareness and behaviour change" topic as impact and possibility to affect end-user behaviour is a must. Another important challenge is to **link DSSs with SCADA systems** so that a DSS uses actual information on the state and operation of water distribution system. SCADA information should be also available for verification of infrastructure models and analyses of network behaviour under different conditions. Systems should enable **near-real-time simulations of complex networks** for online verification of network behaviour and operation under current conditions, in order to verify different management options and take the best possible decision.

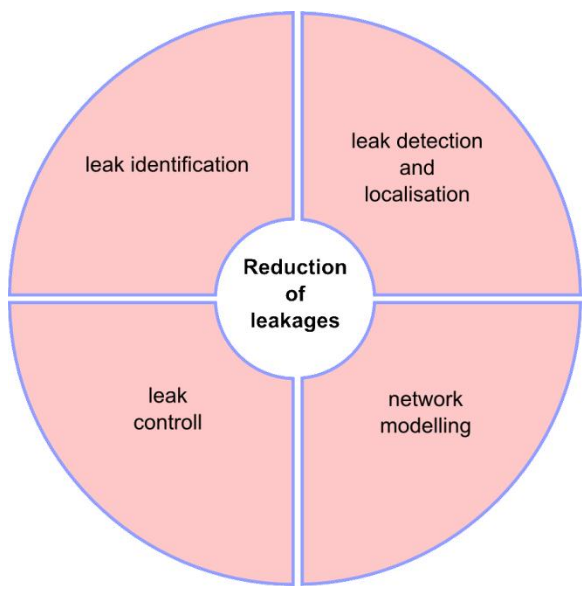

Fig. 10 ICT challenges required to be addressed within reduction of leakages topic

Another emerging topic is **reduction of water leakages** (Fig. 10), that nowadays still account for large amounts of non-revenue water. The most important challenges within this area include **leakage detection and localisation**, which denotes capability of the water entity to identify the leak, based on monitoring of water distribution network as well as to localise its position – e.g. based on pressure analysis, using impedance-based methods or high frequency pipe inspection. The motivation is to detect leakages quicker based on analyses of automated meter readings and supported with decision support systems. Consequently decision support systems need to support **modelling of network behaviour** and support detection of anomalies in water consumption patterns. Fixing the detected leak takes time, so water entities should have the ability to **control water leakages** e.g. through lowered pressure or modified distribution of water.

Reduction of energy consumed in relation to water processing is another emerging topic in application of ICT for water management. According to strategic priorities of H2020 it is expected that energy consumption related to water processing, transportation and consumption should be lowered by 50%. This goal can be achieved through addressing the following aspects of water-energy nexus (Fig. 11):

- reduction of peak water consumption,
- energy recovery,

as well as:

- demand forecasting and management,
- leakage detection and localisation,
- reuse and cascaded use of water.

The last three aspects are common to previous emerging topics, as minimising leakages and promoting reuse or cascaded use of water lowers the demand for water and thus demand for energy required to treat, transport, reclaim and treat the waste water. Demand forecasting and management, on the other hand, allows water networks to be prepared for increased/lowered water availability (through proper demand management) as well as for increased/lowered water consumption, thus optimising energy costs further. Demand management is related to **reduction of peak water consumption** that aims at more even water consumption so that water distribution networks and water resources are not exposed to heavy load/stress during peak consumption. Drop of peak consumption allows reducing energy costs through lower pressure in the network, gives larger control over leaks, and allows using less power hungry technologies (e.g. pumps).

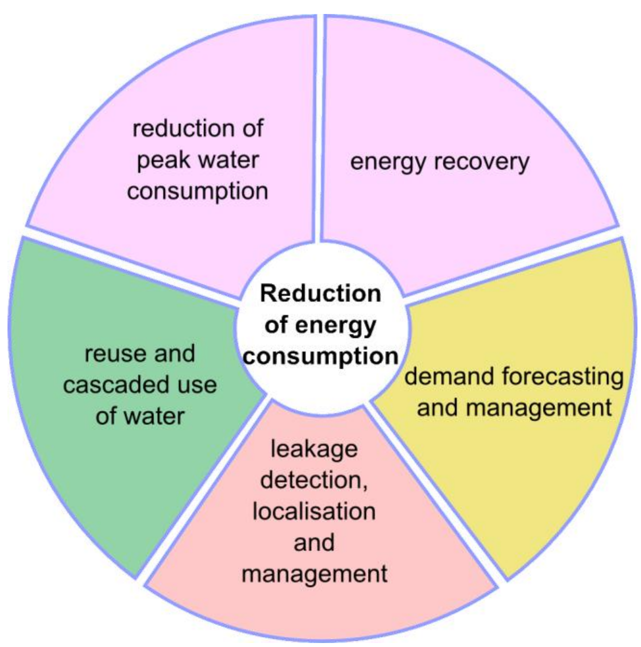

Fig. 11 Emerging topics in Reduction of energy consumption related to water processing priority

4. Technology challenges

Efficient water management requires collection of vast number of data related to water consumption, quality, and energy related to water consumption (for storage, transportation, treatment, etc.). The amount of data collected will increase and this needs to be efficiently managed, stored and used for analysis and improved decision support systems.

Real-time data collection refers to data that needs to be collected in order to provide quick feedback to end-users (inhabitants in each household) in order to increase their awareness and change behaviours. End-users require fast feedback in order to better understand their own water consumption pattern and be able to take measures in order to limit consumption. Data collected will not only include water consumption but should also correlate water consumption to user behaviour and user actions. In this sense information on water consumption should be extended with contextual information. Real-time data is required at household and possibly building level. This detailed information about water consumption and user behaviour should be carefully treated and manipulated to make sure that no privacy issues are raised. Most of the data collected should be analysed, processed and stored (if needed) locally in end-users devices/systems. Aggregated real-time data can be useful at building/suburb level for better understanding its operation as well as for improved detection of water leaks. Real-time data needs to be collected with high frequency and thus meters need to: **communicate wirelessly** (IoT, IoE in order to get contextual information), consume as little power as possible, be battery powered and **capable to harvest energy**.

Near real-time data refers to data collected at water distribution network level that should be collected with frequencies up to several times an hour in order to better model water distribution networks, manage water distribution systems and detect water leaks. This data needs be collected wirelessly and provided to network-level decision support systems and SCADA systems taking care of network operation.

The large number of data collected will require efficient **data storage and processing** that will be able to accommodate large amounts of various data to be stored together with time and spatial information. This requires harmonization of existing systems and unification of data formats and data processing approaches. To accommodate extremely large amounts of data as well as for benefits of DSS systems projects should consider the following approaches to data storage and processing:

- real time data aggregation – amount of real time data will increase quickly it should be considered if all data available is actually needed at various levels of water distribution system. As an example, real time data collected at household level is required for end-user feedback, but may not be necessary for suburb or city level as it can be easily and efficiently replaced with aggregated values, single measurement (e.g. overall household water consumption) and/or less frequent data (taking into account that water distribution network response is much slower),
- correlating water data with contextual and behavioural information for better understanding of water consumption patterns,
- extending measured data with spatial information,
- using new information technologies to speed up data processing and ease data access – data processing algorithm improvements (e.g. parallelization) and efficient implementation (e.g. using GPGPUs, FPGAs, ….)

Data collected and processed needs to be shared across different systems and in accordance with EU rules (see Open Research Data and GEOSS Data Sharing Principles) so that it can be collected once and used many times. This requires clear definition of metadata and preferably unified approach to data storage (formats, types, relations). As a result projects should seek a **common, unified and standardized data formats**.

Collection, storage, processing and sharing of high resolution time and spatial information from water distribution system and on user behaviour may pose **privacy issues**. Therefore projects should seek ICT solutions to ensure secure storage and access to data, fine-grained access control and data anonymization techniques to ensure data is shared on “need to know” basis.

Reduction of water consumption is also possible through water reuse and cascaded use of water. Efficient implementation of these solutions, however, require a number of technological and organizational improvements as well as change in end-user attitudes. The technology is known (with the extreme example of the International Space Station, where more than 90% of water is reused) but lowering the costs and convincing end-users is a must if these two strategies are to be adopted. Last but not least is an **integrated decision support system** that should provide various users at different levels of water distribution network with up-to-date information and ease the management of complex water distribution systems. The system should include GIS, hydrological and weather data, should be integrated with SCADA systems and supervise network operation at different levels (city, suburb, building), use unified data structures enabling seamless data sharing as well as procedures for validation and reconstruction of missing data. The system needs to provide information suitable for every user – water distribution network operator, municipality/government representatives and citizens/end-users.

5. Technology roadmap

Expected technology improvements in ICT for Water Management are presented on Fig. 12. **The first stage** in technology reach will deal with increased and more frequent (near-real-time) measurements of water distribution networks. This will allow for better monitoring and modelling of network behaviour and in return will lead to improved management strategies. Simultaneously, work should be conducted on increasing user awareness and changing user behaviour. **This second step** requires an increased number of sensors per household conducting real-time measurements of water consumption and monitoring user behaviour. This information will allow the provision of contextual meaning for the measured data and generate a feedback that will stimulate the change of behaviours. The number of sensors used will also increase at water distribution network level. Sensors need to provide information on water availability, forecasted weather conditions, water withdrawal, treatment, water available in tanks etc.

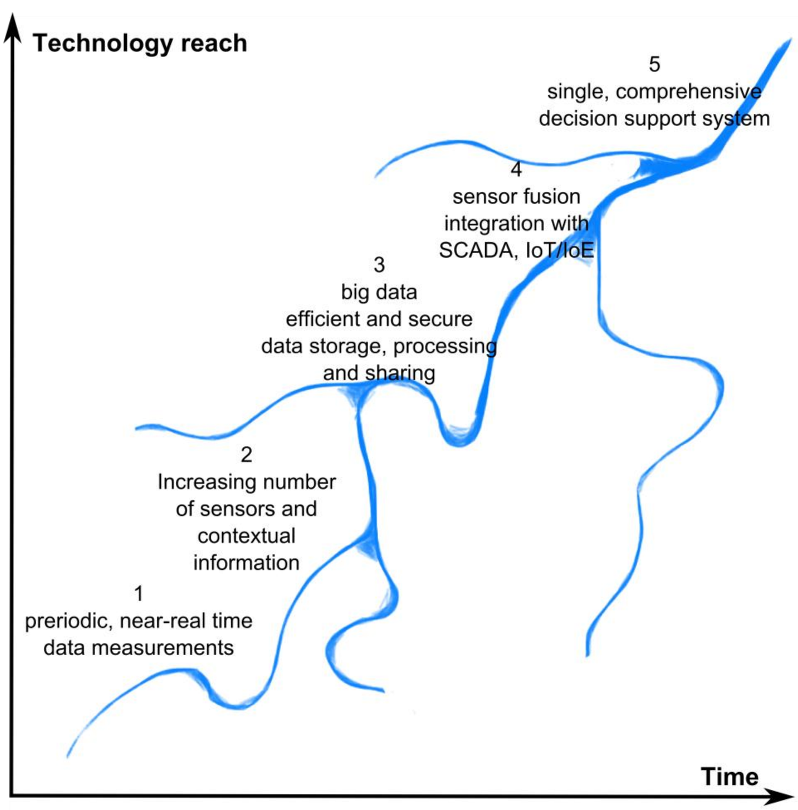

Fig. 12 Technology roadmap for ICT for Water Management

Information on water availability and demanded consumption will be used by water entities in day to day water distribution network management, but also for long term, strategic plans of investments. Since the number of meters and monitors will grow rapidly over the next years there is a need to develop technologies that will be capable to process large amount of data. Therefore, **the third step** will address big data, its efficient and secure storage, data processing and sharing. This should also include data validation, reconstruction and aggregation algorithms as well as unified and standardised metadata description and sharing in accordance with Open Research Data and GEOSS Data Sharing principles. Since data collected will give very detailed view of end-user behaviour together with contextual information, therefore, there is a need for definition of sound and efficient strategies for data access control, methods to ensure data privacy and anonymisation. Works need to pay a lot of attention to privacy challenges as mutual trust is a must when increased end-user awareness and change of behaviour is a goal. From the point of view of WDN the information available will be used for modelling network behaviour, validation of possible management scenarios and to support decision taking. **In the fourth step** the amount of information collected from sensors will increase even further as meters and monitors for water consumption, parameters and contextual information will be integrated with Internet of Things and Internet of Everything (IoT/IoE), providing and sharing large amounts of data. Integration will also apply to DSSs and water network management systems that needs to be connected with SCADA systems that control operation of elements of water networks (e.g. treatment facilities, pump stations, etc.). This integration will provide real, on-line and near-real-time information on water network status allowing for evaluation of various control strategies and support decision taking. **In the next step** all components will be integrated into one, large and comprehensive decision support system. The system will integrate large numbers of diverse sources of information providing support and data processing at different levels of the water distribution chain – from water entities, municipalities, suburb/building managers to end-users and households.

6. Conclusions

Roadmap presented in previous section addresses a broad spectrum of technologies and challenges that are to be addressed in the next few years with the ultimate goal to develop a comprehensive decision support system. In the perspective 2016-2017 initiatives should pay more attention to **water-energy nexus** with main focus on reduction of energy consumption related to water processing. The approach taken should ensure synergy by **addressing both energy and water consumption** reduction (in contrast to previous and current projects that are mainly focused on water). Projects seeking reduction in energy and water consumption should attempt to increase end-user awareness and influence their behaviour. To achieve this, projects should work on ensuring **near real-time metering of WDN** and **real-time metering of households** as well as **collection of contextual information**. Simultaneously projects should work on **efficient data storage** and **seamless data sharing** between systems.