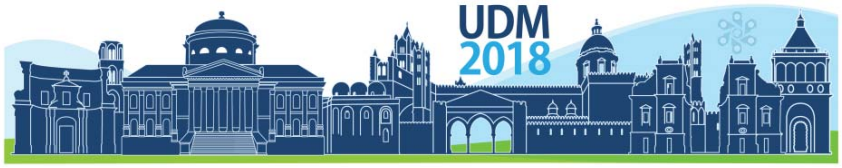

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Frontiers in Urban Drainage - How will Ubiquitous Sensing Change Urban Drainage Management?

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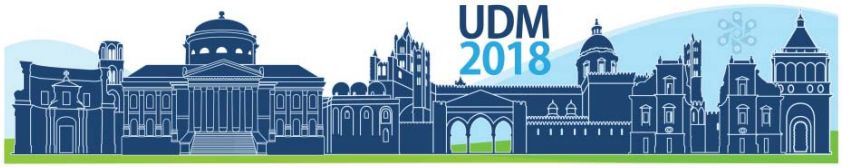
Abstract: In the "internet of things"-future, several billion connected sensors will create many opportunities and threats for urban drainage which are currently not well understood. To identify the most relevant trends, we performed a horizon scan regarding how ubiquitous sensing will shape the future of urban drainage and wastewater management. Our survey of the international got a good response from both the academic and professional communities and shows, that emerging topics for urban water will often involve experts from aquatic ecology as well as IT and computer science. Novel topics either require i) cross-disciplinary training, such as importing new developments from the IT sector, or ii) extended research, such as open questions in aquatic ecology. These results are a call for interdisciplinary research beyond the own discipline. They also demonstrate that the urban drainage community is not yet prepared for the "internet of things" future and a lot remains to be done to harvest the upcoming opportunities.

Keywords: Ubiquitous sensing, internet of things, community survey, forecasting, Horizon Scan

1. FROM GRAB SAMPLING TO UBIQUITOUS SENSING - WHAT TO DO WITH 50 BILLION SENSORS BY 2020?

Traditionally, Urban Water Management suffered from too little data on key variables or boundary conditions, such as current and future serviced population, variability of rainfall or pollutant dynamics. This was mostly, because online process monitoring was either not available, or not observing the true variability or loads into a system. In recent decades, online sensors of water quantity and quality variables have been developed, which offer a much more detailed understanding of relevant processes, such as source and fate of pollutants and provide efficient solutions, such as integrated real-time control (Campisano et al. 2013), and consider pollution from both urban and agricultural areas (Wittmer et al. 2011). Nowadays, communication services, such as GSM, LoRaWAN, and NBIoT, in combination with autonomous energy supplies make it economically viable to collect data from several tens to hundreds of sensors, even in remote or underground locations (Blumensaat et al. 2017).

Unfortunately, the urban water community has not yet fully grasped the value and implications of such information. Data quality control is almost non-existent, gross errors, such as sensor failures, are not detected automatically and, most critically, lacking metadata often renders experimental or routine data useless after a few months or years. Also, many distributed sensors could create security issues and, last but not least, there is not yet an "open science" culture where experimental data are systematically shared with the community. In other words, it is difficult to "learn" from data on urban water systems, because they do not exist, cannot be accessed, or are erroneous.



In the future, these challenges will be even greater due to the “internet of things” communication technologies, which lead to “ubiquitous sensing” capabilities with predicted 50 billion sensors by 2020 (“Internet of Things” 2018). At the same time, such an explosion of sensors will create many opportunities which are currently not well understood (Eggimann et al. 2017). Fragmented examples i) use proxies to infer important system variables, ii) harvest social media, iii) involve citizen scientists and, interestingly, iv) provide feedback to society, which could raise awareness and create a sense of empowerment and 'ownership' among local communities for their water systems.

To better understand these challenges and opportunities, we performed a horizon scan of emerging issues regarding the future of urban drainage and wastewater management.

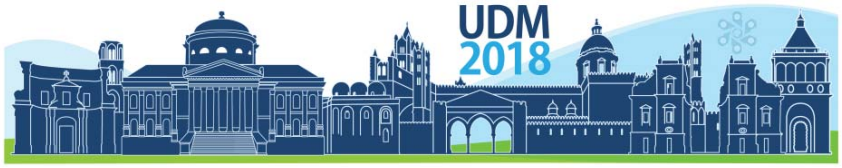
2. ‘HORIZON SCANNING’ TO IMPROVE SOCIETAL PREPAREDNESS FOR FUTURE OPPORTUNITIES AND THREATS

“Horizon scanning is a systematic process that aims to identify potential threats and opportunities relative to a given set of objectives or phenomena to improve societal preparedness.” (Sutherland et al. 2016). Horizon scanning is a common procedure in other scientific fields to identify issues which have just (not yet) emerged in mainstream investigation or debate, but may be important for the urban wastewater community. This is, because it is very realistic that they will occur, e.g. blockchain technology, or because they will have a strong impact on urban water management, e.g. a Bubonic Plague-type pandemic.

Methodologically, we modelled our horizon scan after those of Sutherland et al. (2017, 2016), which is performed annually since 10 years. In a series of first meetings, our core group of seven participants defined the objective: “What are emerging topics related to data that are not yet widely known to the water professionals and could have substantial effects on the monitoring and/or management of urban storm- and wastewater systems.” Then, we proceeded as follows: i) initial collection of topics (n=38), ii) curating topics into a final selection (n=36), iii) consulting the global community via an online survey (see below), also collecting additional topics from the participants, iv) performing an intermediary workshop with a interdisciplinary expert panel and v) data analysis.

The online survey was designed to consult the global community about: i) familiarity with a topic and ii) importance of a topic, i.e. impact on urban wastewater management. Additionally, for each topic, we formulated one possible future scenario, describing how a topic will have manifested in the year 2030 (Vision2030). Familiarity and importance of a topic as well as how desirable and realistic a scenario is had to be indicated with a slider on scale from 0-100. Furthermore, we encouraged the respondents to suggest alternative scenarios and additional topics we may have missed. The survey was sent via email on 22 August 2017 (reminder 8 September 2017) to more than 2000 people in different communities and mailing lists. Respondents were asked to provide answers for all topics if possible, but were also able to skip any theme.

Regarding data analysis, we defined emerging topic as “more important than familiar”. To identify the top ten emerging topics, we calculated the percentage of answers per topic where importance was higher than familiarity. We also identified the top ten emerging topics regarding importance and most feared Vision2030.



3. THE TOPICS

The top three topics regarding novelty were i) Linking Aquatic Ecology to Emissions, ii) Reinforcement learning and iii) Ontologies (Figure 1). The topics considered most important by the community were i) Integrated Management of sewers, WWTP and surface waters, ii) Data Validation and iii) Regulations. The mostly feared visions were those formulated for i) Global Changes, ii) Augmented Reality and iii) Serious Games (Table 1). A detailed description of the formulated visions and survey is available on the OSF project homepage[1].

CONCLUSIONS

In the "internet of things" future, ubiquitous sensing will create many opportunities for urban drainage to overcome the data scarcity it has been struggling with for ages. On the other hand, new challenges arise with this transition. To better prepare for this future, we performed a Horizon Scan regarding emerging topics related to data that are not yet widely known to the water professionals and could have substantial effects on the monitoring and/or management of urban storm- and wastewater systems. Interestingly, our results suggest that a rather classical problem, i.e. the link between emissions and aquatic ecology, is still considered to be "novel" in the sense that the academic and professional communities consider it important, but are not familiar with it. This clearly shows a high demand for further research in this field. In addition, urban drainage should prepare for both push and pull drivers of urban water data collection. In our view, the revolutionary aspect of the modern digitization is that, first, data are now less costly and ubiquitously available, i.e. information on important boundary conditions such as population, or weather, etc., will be pushed through the internet. Second, and more relevant, other entities will be more interested in our data and "pull" urban water management data into external applications. Our positive feedback from the community suggests that Horizon Scanning is a useful exercise. Therefore, the urban drainage community, and especially our associations (e.g. IWA, IAHR) and working groups (e.g. IWGDM, SPN) should discuss who could take over such a foresight/stewardship activity on a routine basis.

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Table 1. The final ranking of topics according to novelty, importance for urban wastewater management and most feared manifestation. It can be seen that there are only few topics which are both unfamiliar and important. Interestingly, topics which relate to computer and information science, e.g. "Cybersecurity" rank comparably high across all areas.

Rank	Most novel topics	Most important topics	Most feared visions2030
1	2.9 Linking Aquatic Ecology to Emissions	4.3 Integrated Management	6.5 Global Changes
2	2.7 Reinforcement learning	2.1 Data Validation	3.2 Augmented Reality
3	3.1 Ontologies	6.1 Regulations	3.3 Serious Games
4	3.5 Cybersecurity	5.3 Resource Recovery	3.6 Complexity – Blind Trust
5	1.5 Micropollutant and Pathogen Monitoring	4.1 Decentralization	3.5 Cybersecurity
6	1.6 Environmental DNA	2.5 Real-Time Models	6.2 Index-Based Insurances
7	3.6 Complexity – Blind Trust	3.5 Cybersecurity	1.8 Explicit Crowd-Sourcing
8	6.5 Global Changes	2.2 Metadata Collection and Organization	2.8 Software Sensing
9	5.1 Secondary Health Benefits	2.9 Linking Aquatic Ecology to Emissions	4.4 Data Collected at Personal Resolution
10	1.1 Onsite High-Res. Mass Spectr.	5.1 Secondary Health Benefits	3.4 Smart Meters and Privacy

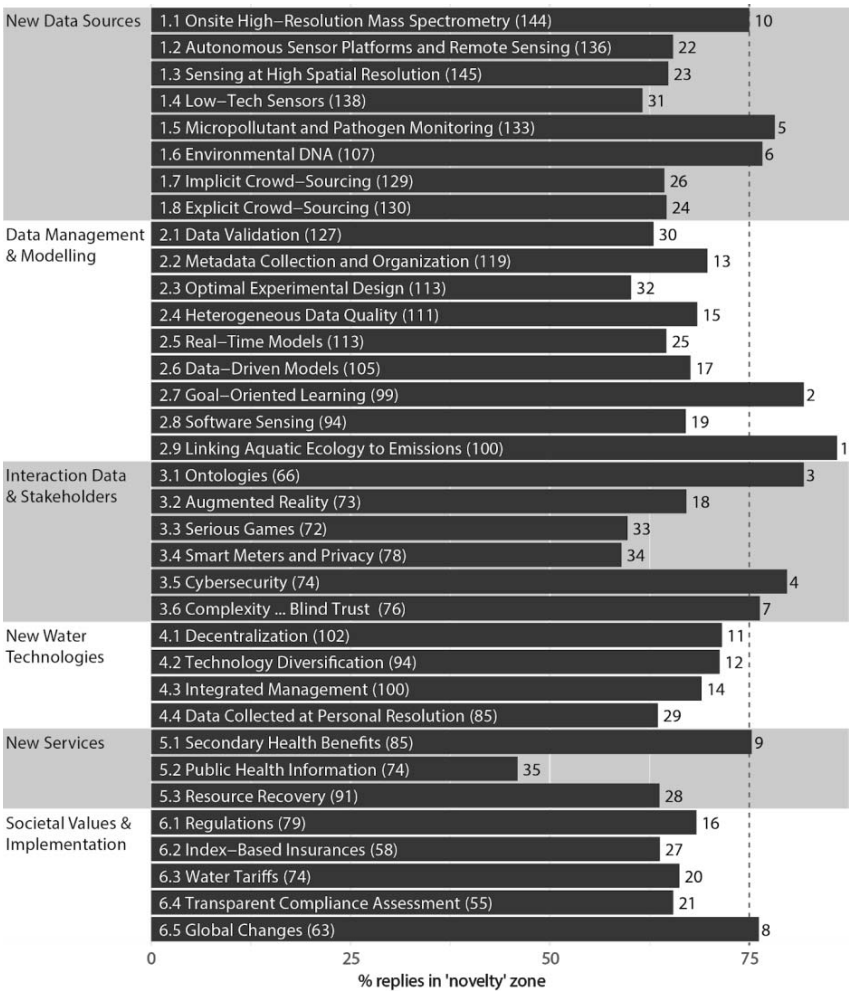

Figure 1. Ranking of Topics according "novelty". The number in brackets indicates the number of respondents per topic, the number at the end of the bar the rank. Participants consider a proper model "Linking Aquatic Ecology to Emissions" (2.9) most unfamiliar, yet important for the field. Surprisingly, other contemporary topics, such as providing unprecedented "Public Health Information" (5.2) from wastewater analysis or transparent compliance assessment via blockchain technology (6.4) were already familiar or considered less important.