The new landscape of wastewater transportation and treatment – a Danish perspective

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Abstract

Our understanding of water's role has been rapidly changing for decades. This paper explores wastewater transportation and treatment within the water cycle. Efforts have been made to redefine this part of the cycle, emphasizing that no water is truly wasted, which has led to new ideas, priorities, and technologies each year. Still however if we think of an ideal defined by "what our hearts believe is good and possible" for water I believe that most people will agree that we are falling well below the bar of that imagined ideal.

I believe the wastewater sector is gradually moving toward this ideal. This progress involves efforts from lawmakers, technology developers, utilities, consultants, contractors, authorities, municipalities, and even water consumers. As traditional views of »wastewater« evolve, the complexity of wastewater management increases. This complexity can lead to difficulties and frustration, but it also offers opportunities for more effective and impactful solutions.

This paper serves as a tool for envisioning and describing how we can advance the water sector toward an ideal future state. It offers a chance to reflect on the gap between our current situation and this ideal. Most importantly, it outlines ten key future trends that guide the way forward.

The paper uses the Utility in Hillerod, Denmark, as a case study to highlight the actions, barriers, and dilemmas utilities face in a practical setting.

Keywords: collaboration, sewers, sustainability, trends, wastewater treatment, water stewardship.

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1. Introduction

Denmark has a strong commitment to sustainability, with wastewater management having been a high priority for decades. This focus intensified in 1986 when fishermen found suffocated lobsters in the Kattegat Sea due to oxygen depletion from eutrophication, causing a public uproar. This event prompted the urgent adoption of the Danish »Water Environment Plan« in 1987 by the Danish government.

Today, 99% of wastewater is treated according to EU's "Urban WasteWater Treatment Directive" and some even at higher levels. For comparison the EU average is 76% and the percentage in Slovenia is 61% (2). Still, Denmark is struggling with the health of its water environment. Recent photos from the bottom of many fiords and seas show a suffocated water environment devoid of plant and wildlife. Despite the high levels of wastewater treatment, Denmark has not succeeded in providing widespread eco-system friendly water and the goal of ecologically sustainable water management is still out of reach.

Still in many ways the story of wastewater management in Denmark is a success story. Wastewater has changed from being a major source of water pollution to becoming a minor source of pollution. Today, the main challenge regarding eutrophication in Denmark is the diffuse flow of nutrients from agricultural fertilizers and secondly pollution from other countries.

Even if pollution has been significantly reduced in the past decades, this does not mean that the water sector should rest on its laurels. There are lots of room for improvement. Additionally, the sustainable transition lowers the bar below which effluent pollution from wastewater must pass. These years increasing pressure on countries, industries, and private people to deliver on the promise of sustainability also means that utilities need to define how they can and will contribute to sustainable wastewater management. The CSRD and ESG directives is expected to push utilities further towards higher ambitions. The sustainability agenda highlights the challenge of operating wastewater systems in a sustainable, efficient, and effective way.

To succeed with the sustainable transition – not just on paper – wastewater management need to adopt the mindset of water stewardship. This means that the job is not done until the waterways actually become "eco-system friendly". This is obviously easier said than done as utilities are not the sole polluter of water systems. Hence, a major challenge lies in establishing collaborative partnerships around water systems and work collaboratively to achieve the goals – not only utility-wide – but community-wide or as has been repeatedly suggested around and between watershed systems.

This means that though actions and methodologies may be similar across different cities and regions, the actual realization will differ from place to place according to the sum total of local conditions.

2. About Hillerod utility

Hillerod Utility is situated north of Copenhagen. The municipality has approximately 50.000 inhabitants, two large pharmaceutical companies, a number of SMEs, a thriving city center and a regional hospital. The city does not have direct boundaries to the sea instead the natural water system and recipients consist of rivers, streams, and lakes. The water from these water ways mostly ends in a northern fiord Isefjord, which is connected to the sea Kattegat north of Zealand.

The city is undergoing major changes these years not only due to the sustainability transition, but also as city is growing in number of inhabitants, the industries are experiencing rapid and large growth. The hospital is being rebuild as a new regional "super-hospital". The political system has been experiencing a long political controversy about the type of sewer system that the city should apply. This controversy has caused a pause in the development and a new redirection of the efforts of developing the sewer system.

On the wastewater treatment side, a major expansion is taking place to accommodate the increased wastewater load from the industries and inhabitants. The increase in nitrogen load is approximately 30%, while the increase in phosphorous load is approximately 60%.

Additionally, the Danish government has demanded that the six new regional super hospitals need to have quaternary wastewater treatment applied to treat the wastewater for pharmaceutical residuals. In Hillerod it has been decided to implement this by mandating the city's main wastewater treatment plant to add quaternary treatment. This strategy is applied to ensure a better and broader effect as most pharmaceuticals are not taken at hospitals but in private homes.

Additionally, sludge treatment and deposition, which has until recently been handled by an external service provider for decades, has been returned to the utility as a new task. Due to problems with PFOS and PFAS, the available capacity for sludge treatment in Denmark by external suppliers is non-existent the coming years as it has been reserved for contaminated sludge. Therefore, the utility is in process of establishing local means to take care of its sludge.

All these simultaneous projects require the staff to rethink and rebuild both the sewer and wastewater treatment system. The burning question is how do we do this in the best way possible – and what would even define what is best? This complex process needs to be carried out under high time pressure as the surrounding city requires the system to be functional to grow and develop. So, while it would be wise to slow down and analyze the system and the situation, there is simply a lack of time to 'get to the bottom' of it all.

The utility has adopted a strategy aligned with municipal plans and strategies. The utility strategy points to a clear vision of high levels of sustainability. The overarching goal of the water part of the utility (the utility also includes energy and solid waste) is 1) Better conditions for the water environment and nature and 2) Enough and clean water for now and in the future. These goals are very clear, and the commitment is high. The aims are however obviously tempered by restrictions of economy, regulations, existing systems, political priorities, operability and operator acceptance, availability of competences, customer demands and the type of "disturbances" that is always coming from the surrounding stakeholders.

A combination of solutions is applied to the concrete situation of Hillerod Utility. This includes some major solutions such as:

- the plant capacity is extended using Integrated fixed film activated sludge (IFAS),
- the xenobiotic removal in the quaternary treatment step is implemented by a combination of activated carbon and ozone,
- CSO's are experimentally treated decentralized by Sedipipe systems.

Even more interesting than the technical solutions are the emerging trends and thought processes guiding these solutions as the utility navigates this complex process. These trends and key ideas reflect broader developments happening in Denmark, the EU, and worldwide.

3. Top 10 trends in wastewater management

Examining the overall trend in water system management toward water stewardship—striving for »what our hearts believe is good and possible«—we can identify ten emerging principles in wastewater management. These ten trends are summarized and elaborated upon in the following sections.

3.1 Stakeholder collaboration and eventually co-creation

The overall trend goes from thinking and working as a singular independent organization towards extending collaborative arms out to work with stakeholder organizations with the aim of solving water related problems jointly.

The water utility sector – as other utility sectors – are increasingly working collaboratively between organizations. Earlier the utilities were much more compartmentalized and working towards optimization of own internal processes. This has led to a significant growth in domain knowledge and each domain like sewer systems and wastewater treatment plants has increased in process efficiency – both regarding the water processes taking place and in terms of the work processes around these physical, chemical, and biological processes.

The trend is that to reach effectiveness there need to be collaboration across industrial boundaries, sectors, and stakeholders. To succeed with creating results in terms of eco-friendly results in the natural or semi-natural parts of the environment served and exploited by utilities, is only possible if more actors (organizations) work together. All major environmental issues are the result of several actors and can only be solved by joint commitment and collaboration.

Example: Denmark is famous for fostering the concept of the industrial symbiosis. The idea originated in the municipality of Kalundborg but has spread to other municipalities including Hillerod. In the description of the symbiosis in Hillerod it is stated that: "An Industrial symbiosis describes a symbiotic relationship in which wastes or by-products of one industry or industrial process become the raw materials for another. Application of the concept allows materials to be used in a more sustainable way and contributes to the creation of a circular economy" (2). In the described transition process, there are a lot of collaborative efforts on water production, water savings and expansion of the wastewater treatment plant with additional capacity and the capability to treat pharmaceutical residuals.

3.2 New pollutants in focus

This trend goes from a narrow understanding of role of wastewater treatment limited to issues of reducing nutrients and oxygen demanding organic matter to treatment of the whole range of xenobiotics by new technologies. As such it extends the historical development of wastewater handling from 19th century purposes of just getting the waste out of cities.

Technological development of processes to remove pharmaceuticals are focused primarily on ozone, activated carbon and membrane technologies. The technologies have different pros and cons. A major difficulty with the removal of xenobiotics that makes it different from the more classical wastewater substances like nitrogen, phosphorous is that xenobiotics in wastewater involves hundreds or even thousands of different substances. The level of removal for each of these differ from substance to substance and technology to technology. And the quantification of the substances are riddles with great difficulties due to the multitude of substances, the low concentrations and corresponding detection limits. Addressing xenobiotics is a completely new challenge to the water sector. This adds a major new treatment step that are very different in both scope and operations compared to the current/old systems.

Example: in Denmark all super-hospitals need to have their water treated in a quaternary process for pharmaceutical residuals. That is the residuals that patients taking pharmaceuticals secrete. This includes the actual active chemical agent as well as all types of degraded byproducts as well as substances established by cocktail effects. This means that utilities like Hillerod have been tasked with establishing this treatment step as well as – at least collaboratively with the municipality attempt to define realistic effluent demands on the treatment step.

3.3 Using models on all levels

While modelling is not new per se, there is a major change happening these years. The trend goes from modelling sewer systems and wastewater treatment systems as a hopeful but often futile exercise to a situation where models and digital twins are realistic and are being actively used for decision making on strategic, tactical, and operational levels.

The term "Digital twins" has emerged over the last few years. A living digital twin delivers a system that is in online communication with the real world, so that what you see in the model mirrors the actual status of the system. Based on that it is possible to calculate scenarios, eg what happens if it rains? Or what happens if the city develops in this way or that way? Or what happens if we take out a treatment lane of operation for a period of time? Additionally, these models can now be used for design purposes.

Example: There are examples in Hillerod from both wastewater treatment and sewer systems. In Hillerod especially the sewer system modelling is having a major impact on every decision on developing and designing the systems. For years the focus (and conflict) has been around separate sewer system, where wastewater runs in one system and rainwater in another. When increasingly reducing the rainwater in the sewer systems the number of combined sewer overflows will be reduced and the ecological state in the receiving river will be less loaded with oxygen depleting pollution and nutrients. To design the most optimal system, models need to be set up based on true knowledge about the sewer system. This is: what are the dimensions of pipes, what are the x, y and z position of each node, how are the pumps controlled, how is the weirs constructed etc. Getting to a point where this matrix of information is stored correctly in a geographical information system has so far been limiting the trust in the models. In Hillerod a major one-year project laser-focused on providing data and models that are true has been undertaken. No models are ever perfectly true, but it has been a quantum leap forward to establish a "good enough model". Based on this new model it is possible to experiment to find the best design and operations solutions.

3.4 Water reuse

Water reuse is still an emerging technology, so far only used as a last option in water sparse areas. However, the trend of going from "wastewater in – cleaner wastewater out" towards water reuse is coming within grasp.

Such a trend may have transformative powers over how we design and operate the urban water cycle. Though this is probably not where it will end, one could in principle imagine an 'eternity machine' with the urban water consumption eventually not touching the natural water cycle – there could be a separate technologically controlled water loop, not drawing water resources and not contributing to the environment with polluting substances.

Example: In Hillerod and the northern part of Zealand the groundwater is overused. This means that the water extraction from groundwater resources that is taking place is not long-term sustainable. Therefore, it is extremely difficult to acquire new water extraction permits effectively halting the development of the area – or alternatively running a system with detrimental effects on the groundwater resources. As quaternary treatment systems are being applied the effluent wastewater jumps upwards in water quality except the salt contents being too high, (which is a manageable problem), the water quality is coming very close to the standards of drinking water. This means that within a few years from now, it may be possible to reuse the treated wastewater at least for some industrial purposes.

3.5 Sustainability governance

The transition regarding understanding the concept of sustainability has taken place since the word "sustainability" entered the global scene with Gro Harlem Brundtland in 1987. So, while this is not a new word, something new is happening with the word these years. Intuitively, we understand the word, however, that is not very helpful when we are to give priority to one type of sustainability over another – or even finding a balance between a whole array of sustainability factors. It is moving from a fluffy concept to a concept with harder definitions. In utilities similarly it is moving from a blurry understanding to now, where we are working with sustainability definitions, targets, monitoring, documentation etc.

It is interesting to compare this situation to the history of modern financial accounting principles. These were not developed until the 70s and 80s. Something that we take for granted today has only been around in this form for about 60 years. Similarly, the new ESG framework from EU puts forward principles for sustainability accounting based on Environmental and Social factor and ensuring proper governance. Environmental factors are for example Climate Change Mitigation and Adaptation, or Biodiversity Protection. Social factors are for example Labor practices or Community Engagement. The corporate governance principles promote transparent and accountable corporate governance structures. The principle of "Double materiality assessment" is part of the ESG framework, which mean that companies and utilities need to consider the sustainability effects from two points of view. They need to consider how environmental and social issues (like climate change, resource scarcity, or labor practices) can impact the company's financial health. The other aspect is that they need to consider how the company's activities affect the environment and society. So, it is like a two way street.

This way of accounting will eventually spill over to how we design wastewater solutions. Design will eventually be governed both by traditional financial considerations and sustainability considerations. The days where it was easy to claim that this or that is an unspecified degree of sustainable are counted. Communication around the real environmental and social impacts will be more and more transparent as well as "fair and true".

The ESG framework is expected to also facilitate accounting of the total sustainability impact for the wastewater systems – both positive and negative. It will then become normal practice to measure better, set clearer goals and fight harder to reach the goals.

Example: in Hillerod utility the first experience with ESG is present as the first CO2 equivalents accounting for scope 1 and 2 has been prepared. But even without the ESG framework the pressure for finding suitable measures and definitions for sustainability is pressing. The wastewater treatment plant is fully covered. To stay true to that a building is being constructed for the quaternary treatment step. This is carried out according to the DGNB standard, which is the German sustainability standard for buildings (similar standards in different countries). At the same time the same is being done for a new water works. This raises hundreds of interesting questions such as questions about choice of construction materials, comparing different constructions and how to include the social dimension of sustainability. Questions that, though we are in a way in the 'business of sustainability', we do not always have answers readily available for.

Five smaller trends that are also worth being on the lookout for are:

3.6 Eco-informed design

Moving from standard design and design criteria based on law and industrial standards are being superseded with designs based on deeper ecological and environmental understanding. One example is that Hillerod utility has found that though the reduction of combined sewer overflows will reduce nutrients load and oxygen consumption, there may be other factors that are even more important. From an ecological perspective, a more effective measure may be to ensure better light conditions by removing a few overshadowing trees and improving the riverbed to ensure better spawning grounds and variable flow conditions. Such alterations cost a fraction of separating rainwater but may have a much larger effect. This however requires that the owner of the river is willing to collaborate.

3.7 Partnering

An important trend is that our contracting work is moving from 'adversarial' contracting forms leading to conflict upon conflict around quality and cost to partnership with consultants and contractors. The new collaborative form works by aligning financial incentives, establishing temporary "working as one"-organization setups and consciously building trust in relationships. Partnering is a much more trust-based way of working and when these collaborative forms work, they ensure better solutions, better economy for all partners and much better workplace environment. The utility is also using this method to ensure higher speed of execution. Since the partnering framework regulates earnings, it is not necessary to have the full detailed design ready before entering with contractors. Instead, contractors take part in the design process. This further improves the design and significantly reduces the risk of design conflict later.

3.8 Holistic approach to energy and climate

Earlier improving efficiency and reduction of operations cost meant attention to energy consumption. As this has come increasingly under control the focus is now changing to a more holistic view on the problem. That means that scope 3 emissions (i.e. emissions of the construction process) comes into play. Also, methane, laughter gas and carbon dioxide from the processes comes into play and the varying degree of emitted CO2 emissions from electricity over time is used in optimization of control.

3.9 New management principles

New management practices are required to steer this new reality. There is a need for more employee autonomy to be able to work in new ways and with new problems. Top managers are not able to efficiently orchestrate this complex work. In Hillerod Utility the organizational principles are still hierarchical, but the way that the hierarchy is administered is much more in the spirit of autonomy and independent collaboration. Still the hierarchy serves as organizing principle to avoid chaos and to ensure information flows for company critical decisions. How such an organization will look and operate in 5-10 years may be much different from what we see today. It is important to experiment with new management principles looking towards more transparency, higher degrees of employee engagement in strategy development and decisions, autonomy, and independence.

3.10 Wicked problems

Water utilities are being shaken up. From living as somewhat sleepy slow-moving conservative companies, the speed and complexity is picking up. Utilities are increasingly experiencing themselves as being entangled in various complex or even "wicked problems" with a host of other stakeholders. The definition of wicked problems is relevant to reflect upon as a backdrop to the above trends.

A wicked problem is characterized by being one or more of the following:

Complexity: They involve many interdependent factors that make them difficult to address comprehensively.

Uncertainty: The information needed to understand the problem and its potential solutions is often incomplete or uncertain.

Interconnectedness: Changes in one part of the problem can have unforeseen consequences in other parts.

No Clear Solution: There is no definitive solution and attempts to solve the problem can lead to new issues.

Stakeholder Disagreement: Different stakeholders have different perspectives and values, leading to conflicting views on how the problem should be addressed.

Unique: Each wicked problem is unique, meaning solutions that work for one problem may not work for another.

3. Conclusion

In conclusion, the landscape of wastewater transportation and treatment is undergoing a significant transformation, driven by technological advancements, regulatory changes, and an increasing commitment to sustainability. This paper highlights the multifaceted efforts required to approach an ideal state of water stewardship, where wastewater management not only meets regulatory standards but also contributes to a healthier, more sustainable environment.

The case of Hillerod Utility exemplifies the complex challenges and innovative solutions being implemented in Denmark. From the integration of advanced treatment technologies to the adoption of sustainable construction standards and collaborative partnerships, Hillerod is navigating the intricacies of modern wastewater management. This reflects a broader trend seen across the EU and globally, where utilities are moving towards more holistic, eco-friendly practices.

The ten emerging principles outlined in this paper—from stakeholder collaboration and new pollutant focus to sustainability governance and the recognition of wicked problems—provide a roadmap for the future of wastewater management. These principles emphasize the importance of adaptive, integrated approaches that consider both financial and environmental impacts.

As the field continues to evolve, it is clear that success will depend on the ability to innovate and collaborate across sectors and disciplines. By embracing complexity and fostering a culture of openness and innovation, utilities can play a crucial role in achieving sustainable water management goals.

Ultimately, the journey towards this ideal state is ongoing. It requires a commitment to learning, adapting, and pushing the boundaries of what is possible. By building on the progress made and addressing the remaining challenges, the wastewater sector can significantly contribute to a more sustainable and resilient future for all.

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