Chapter 8

Wicked Water Systems: A Review of Challenges and Opportunities

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Additional information is available at the end of the chapter

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Abstract

The contemporary urban water system is under extreme pressure due to growing demand, climate change, and social inequality. Conventional methods to mitigating extreme water events have proven to be insufficient to safeguard our growing urban centers. Unless the competing demands and pressures of the urban water system are addressed in holistic manners, we will soon lack of access to good-quality water, and extreme water events will increasingly affect our metropoles, with most severe consequences for communities already living in marginal conditions. This chapter takes as point of departure that the future urban waterscape is a wicked problem in which actions taken to mitigate the problems are often inadequate and temporary, even when they are the result of the public debate and shared concern. The current urban water system has reached a critical threshold, but how can innovative urban water design or planning solutions be implemented when there is so much at stake? The chapter will address the urban waterscape, its contemporary challenges and what we can expect in future climate conditions. Furthermore, we will discuss contemporary solutions as well as highlight the sociopolitical, economic, and ecological barriers to their implementation. To illustrate the challenges as well as the range of solutions, we will present the algal blooms in Lake Erie, USA, as a case study. We will end with an elaboration on how to innovate in the case of wicked problems.

Keywords: wicked problems, water, urban design, innovation, algal blooms

1. Introduction

On 25th of August, 2017, Hurricane Harvey made the first landfall in Texas. Although Houston, a city of approximately 6.5 million inhabitants, lays above sea level, it experienced massive floods over the following days due to the extreme amounts of rain and wind and storm surge [1]. Simultaneously, Nepal, India, and Bangladesh are struck by heavy monsoon rains, causing Mumbai's streets to turn into rivers and more than 1200 deaths throughout the entire region [2]. Houston's extreme floods were caused by the combination of heavy rains causing interior waterways to overflow, a storm surge that prevented them from emptying out in the ocean, and a general lack of pervious surface in the city [3]. Mumbai vulnerability lays in its rapid expansion that is accompanied by construction and development on floodplains as well as clogged waterways due to an excess of plastic waste [2].

The contemporary urban water system is under extreme pressure of rapid urbanization, growing demand, climate change, and social inequality. It has become apparent that water is no longer a free endless resource and that waste cannot just be transported to other places, because water systems are globally connected [4]. Unless the competing demands are addressed in holistic manners, we will soon lack access to good-quality water, and extreme flooding, droughts, and tsunamis will increasingly affect the planet and its people, with most severe consequences for those already living in marginal conditions. Disempowered communities, minorities, and the poor are at the frontlines [5].

The urgency of this has been recognized at the recent Climate Summit in Paris. Commitments have been made by governments and other stakeholders, but the tensions underlying our failure to address these issues in the past have not been resolved, and the implementation of radical policies and integrated innovations remains to be seen. Interventions and implementations are challenged by the uncertainty of climate models, cycles of capital investment and governmental risk aversion, fragmentation of governmental responsibility and inclusion of knowledge, the definition of innovation, and scale.

We can think of transforming the urban water ecologies to meet the needs of our future cities as a wicked problem, a term first introduced by Horst Rittel, a German scholar, in the 1960s [6]. Wicked problems are not easy to formulate or to reach a consensus on a solution. Actions taken to mitigate the problems are often inadequate and temporary, even when they are the result of the public debate and shared concerns [7]. Rittel defines some characteristics of wicked problems. First, one cannot understand the problem without understanding its context. There is no way of first understanding and then solving since the existing pieces might shift in a solution.

Second, there is no stopping rule. In the case of a wicked problem, it is not clear when a solution is found. The intervention does not stop when the problem is solved but is limited by external factors such as time or money.

Third, there are no true or false answers since the criteria to determine that do not exist. Any judgment by actors is determined by the values and objectives of the group that they are part of, the place they take within the realm of the existing problem.

Finally, there is no test (except for real-life implementation) to a wicked problem. Every attempt will have consequences that are either desirable or not, which will then trigger another set of consequences. Every implemented "solution" will leave its mark in the system [6].

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For example, the Dutch and the storm surge barrier they decided to build in the 1960s after a devastating storm with 5-m waves broke the existing dikes and had affected many lives in the South of Holland in 1953. Holland had lost the battle with water in a storm that was beyond their expectation. This called for an intervention outside of what they already knew. During the process of implementing the barrier, all types of issues arose such as a changing hydrology causing strong tides as the project proceeded, complicating further intervention. Although, until this day, that levee has protected the low-lying south of the country, it is a continuous train of intervention that has been implemented to secure the Dutch with dry feet [8].

The current urban water system has reached a critical threshold, but how can innovative urban water design or planning solutions be implemented when there is so much at stake? This chapter will first briefly discuss the value of water. Second, it will address the urban waterscape and its contemporary challenges. What are contemporary urban centers facing in terms of water pressures, and what can we expect in future climate conditions. Furthermore, we will discuss contemporary design and planning of solutions as well as highlight the socio-political, economic, and ecological barriers to their implementation. To illustrate the challenges as well as the range of solutions, we will present the algal blooms in Lake Erie, USA, as a case study. The chapter will end with an elaboration on how to innovate in the case of wicked problems.

2. The value of water and what is at stake

There is a certain dualism at stake when thinking about water and cities. Water needs to get into our urban systems and flow through them, for otherwise urban populations cannot exist; think about drinking water or water needed for urban industries. On the other side, we also need to be protected against it. Too much water, in the form a natural hazard or a polluted body like sewage, is a constant threat to society resulting in inadequate attempts of controlling the flows.

Water has multiple physical attributes that affect its relation to the human body and environment and that shape its use [9]. Its fluidity and plurality are reflected in the ways we refer to it. Water is experienced (tasteless, odorless, cold, salty), and it is volatile in its form (rain, ice, and gas). It moves at different speed (current, wave, mirror), has a carrying capacity (of nutrients and pollutants), and is an active agent (flows, shapes, erodes, moisturizes), which can also be contained (in soil pores, pathways, and rivers).

The fluidity and plural attributes of water are at the core of distribution of quality and quantity of water that is of key importance to maintain the integrity of ecosystems and that will preserve their ability to provide services valuable to humans [10]. Natural water supplies vary over times as these flows cause scarcity and in other places floods. The fact that water has a certain carrying capacity allows it to carry nutrients, but it also allows it to erode our coasts resulting in turbid currents. Large technical infrastructures, such as dams, reservoirs, and artificial storages, shield us from the variability of the resource and protect us against floods [10].

Historically, all large urban centers were built in the proximity of water for it to survive. When ancient Rome around 300 BC grew beyond its capacity to provide fresh water to its citizens locally, the Romans engineered an extensive system, including large aqueducts, underground pipes, as well as measures to control the velocity of the water to import water into the city [11]. This infrastructure had a combined length of over 400 km and brought water from places as far away as 80 km [12]. There was one major pitfall to their ingenious water system; many of the pipes were made from lead, a strong neurotoxin, which contaminated the water and poisoned Rome's inhabitants [13]. Some scholars advocate that lead poisoning was at the base of the fall of the Roman empire [14]. Lead poisoning is not only a problem of the past as was seen in Flint Michigan in 2015. The local government switched their water resource to a more affordable but corrosive option, the Flint River, which caused the pipes to leak lead into the drinking water [15].

3. Contemporary urban water systems and future threats

All water is connected and so are the issues surrounding our water systems. What are the pressures threatening our urban centers exactly? As mentioned before urban areas face issues regarding the quantity and quality of water manifesting itself in scarcity, pollution, and flood events.

First, flooding events are caused by a multitude of factors, including water body flooding and heavy rains, but also factors that are related to the urban fabric itself such as clogging of drainage systems and land use change. Although there is no exact prediction of what will happen in the light of climate change, most scientists agree that extreme weather events such as hurricanes will occur more frequently and will be of higher intensity. Additionally, more extremes in precipitation will occur (both droughts and excess) and a rise of sea level which will most rapidly affect coastal cities and small island communities [16]. At the same time, rapid urbanization leads to expansion of the urban surface which often results in a lack of stormwater retention space due to imperviousness of the surface that simultaneously accelerates stormwater flow, keeping the water in the streets. Excess waste is at the base of clogging the existing man-made drainage channels and natural systems such as mangroves or wetlands [17].

Jongman and colleagues [18] address the rise of costs (infrastructure, housing, businesses, etc.) as a result of flooding throughout Europe. They suggest that by 2050, those annual costs will rise from 4.5 Billion to 23 Billion Euros, under the anticipated climate change and socio-economic development [18].

An abundance of water can be problematic but so is scarcity. In some cases, cities experience both. Cities often rely on sources in their hinterlands to supply their population, industries, and agriculture with fresh water. However, our fresh water resources are decreasing. We

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have consumed water without limits under the assumption that it is a renewable resource. Moreover, growing cities along with a growing population increase the need for fresh water. In response, cities have created complex large-scale infrastructures trying to reach new sources of underground water or surface water [19]. When surface water is insufficient for the demand, cities often turn to groundwater; however, when more water is consumed than what is refilling the source, this will not only result in depletion and water stress in the future but also to saltwater intrusion and soil subsidence of lower lying areas as well as to negative effects on natural streamflows and depended ecosystems [20, 21]. In a capitalist society, consuming less water is hard to achieve, since it is in direct opposition to the principles on which such society is based [22].

Furthermore, human activities such as irrigation and industrial use threaten the global water systems. The benefits of our water use to economic growth go hand in hand with degradation of our (aquatic) ecosystems that will result in major costs in the future [23]. Think about micro plastic that enters the water system through our waste systems. These fragmented particles are almost impossible to filter out of the systems, and we have yet to understand the largely unknown long-term consequences [24].

Apart from synthetic pollution, pollution can also occur by a disbalance of nutrients in the water. An example is Toledo, a city of a little over 500,000 inhabitants in the US. The drinking water source for the city is the adjacent Lake Erie, but in 2014 the inhabitants had to close their taps because of the presence of microcystin, a toxin that emerged from algae blooms occurring in the lake [25]. These blooms are caused by nutrient runoff, phosphorus, in particular, that flows from urban sewage overflow (point source) and predominantly agricultural runoff (nonpoint source) through the watershed into the lake and are intensified by heavy rain. Climate change, extreme weather events, and hot summers will cause harmful algae blooms to occur more often and more intense within the following years [26]. We will review this more in-depth in the following sections.

Summarizing, floods, pollution, and scarcity are all interconnected, e.g., in the case of floods, it can pollute water bodies when hitting a chemical factory. Pollution in its turn leads to scarcity of freshwater.

How can we secure healthy water system on our planet in a changing world?

4. Mitigating water stress

Stable socio-environmental ecosystems do not exist; these systems are always on the move. Society wants to influence the ecological system by implementing measures to alter the hydrological response and to keep it at its highest stage of productivity, preventing it from collapse [27]. The implementation measures are often incentivized from an economic efficiency agenda and are predominantly technocratic as they often fail to fully integrate social dimensions of water. Furthermore, they are often narrow solutions that are unsynchronized with the dynamics of the physical landscape.

Mollinga distinguishes three dimensions at the heart of water control: technical/physical, organizational/managerial, and a socioeconomic and regulatory [28].

Historically, water infrastructure and projects to alter the hydrological response have been created by scientific and technical experts, emphasizing rational science and economic efficiency. With the increase of tension between social, environmental, and economic elements in urban areas, this is no longer viable. Implemented infrastructures have more often redirected the system than stopped it from developing. Again and again, the effect of one intervention has asked for another one as systems are successional and dynamic [29].

There are four dominant ways of altering the hydrological response through physical implementations:

1. inverting the course of the water flow to get water supply (e.g., irrigation);

2. altering the stream network (wetlands);

3. altering the drainage basin (dams); and

4. changing the global climate (overusing water) [28].

Furthermore, innovation in urban water systems comes in three ways: (1) new technologies (desalination or new waste water systems), (2) new management approaches (business models, policy implementations), and (3) techniques to increase the functioning of the current system (monitoring, etc.) [30].

The large-scale infrastructure-engineering approach was overtaken by more recent notions of conservation or restoration. In both, system ecology remains entrenched within the same modern paradigm that many argue is the structural cause of environmental and social decline, as Corner puts it "whereas conservation utilizes ecology to facilitate further control over the human environment, restoration uses it to provide rhetorical force to emotional feelings about the primacy of nature and the errors of the Anthropocene" [31]. Thus, conservation aims at keeping the same ecosystem services of a system and tries to keep a system from moving away from its current state. It has faith that adaptive and transformative measures will save the day [32].

In both the large infrastructure/engineering and conservation/restoration trains of thought, the symptoms of ecological distress are dealt with, while causal and cultural foundations—the social structures that underlie at these problems—are often not addressed.

The problematic at stake with the drinking water systems of Toledo, Ohio, provides a good case study of proposed interventions and barriers while working with unprecedented issues and wicked problems. In 2016, as part of Enaegon, a collaborative urban design company with a focus on water, we proposed an implementation that would contribute to diverting the algae blooms in Lake Erie. We took as a point of departure that wicked problems can be challenged throughout the journey toward a design intervention that can change the interactions in the systems. The outcome is not necessarily a solution but can help better understand the wickedness of the problem and form the basis of new experiments.

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4.1. Case study: algae blooms in Lake Erie

In the first weekend of August 2014, the residents of Toledo, Ohio, were advised not to drink the water from their faucets due to high levels of microcystin, a toxin that is caused by algae blooms in the source of their drinking water, Lake Erie. People prepared for days without water, standing in lines at grocery stores. Some even crossing the border to Canada, packed with as many empty containers as they could find [33].

When the local authorities announced the drinking water ban, no indication of its duration was given—local government simply did not know. They had to wait for the US Environmental Protection Agency (EPA) to run tests and approve the drinking water. This was problematic since there was no standard for what was a safe amount of microcystin in the water. The only standard that did exist was the outdated standard instituted by the World Health Organization [34].

This process that causes harmful algal blooms in Lake Erie is called eutrophication, which can be defined as an increase of organic carbon production (this is basically everything that is alive from plants to animals to humans) in an ecosystem [35]. Although higher production is often seen as a good thing (as it is sometimes referred to as nutrient enrichment), in this case, its side effect is algal blooms that in the end lead to hypoxia, the death of a water body.

Eutrophication is caused by nutrient runoff from farming operations that involve intensive fertilization with both manure and chemical fertilizer, as well as sewer overflow from adjacent urban areas. The International Joint Commission (IJC), a binational advisory body on the great lakes water quality agreement, estimates that 61–84% of the nutrient runoff is caused by agricultural runoff whereas only 16% flows from combined sewers of the surrounding cities [36].

Most of the runoff happens in spring due to extreme rain events, flushing the phosphorus into the agricultural fields and drainage ditches due to surface and subsurface flow. In the case of Lake Erie, it is the Maumee watershed that is the main tributary due to extensive farming operations (80% of the land is under cultivation) in the region. All the ditches in one watershed flow toward the same point, the Maumee River, and then into Lake Erie at the Toledo waterfront [36].

Although 2014 was the first time that drinking water system got severely affected, algal blooms have been happening for decades. Due to ongoing urbanization and the dumping of untreated sewage around the lake's shoreline, more extreme algal blooms started to emerge in the 1950s and 1960s. Lake Erie's oxygen-depleted waters and its changing ecosystems even caused it to be declared dead by the beginning of the 1970s [37].

It is not only drinking water that is jeopardized. Algal blooms will trigger economic losses through a decrease in tourism (who wants to swim in a toxic lake?) and a declining fishing sector since these algal blooms pretty much affect the whole ecosystem by depleting oxygen, killing other species and ultimately "killing" the lake [38].

Thus, the main problem lays with the farming practices and farming policy, but the consequences lay in the drinking water supply for the communities that are reliant on Lake Erie as their drinking water source.

So what is the plan? The Ohio Sea Grant on Social Network Analysis of Lake Erie HAB's Stakeholder Groups has identified more than 150 stakeholders that are more or less involved (and yes we are only talking about the Maumee Watershed) [39].

The International Joint Commission (IJC), a collaborative advisory body between Canada and the USA, existing of a variety of experts ranging from scholars to politicians to experts from the private sector, has stressed the urgency of a 41% decrease in nutrient runoff to alleviate future algal blooms and safeguard drinking water quality. The majority of agricultural runoff is generated by farmers in the Maumee Watershed which borders the states of Indiana, Michigan, and Ohio; the IJC has designated this watershed the number one area of concern [36].

However, this is a concern without a solid action plan or timeframe for its resolution.

The federal government claims to have acted on the urgency with a response through bilateral agreements and complex funding mechanisms. In 2012, the US EPA and Environment Canada signed an updated version of the in Great Lakes Water Quality Act (GLWQA); the agreement bound them to develop detailed commitments in 2016 [40].

Strangely enough, these new commitments have been made to achieve the 41% reductions in nutrients but fail to put a deadline to the proposed action and therefore also lack sanctions if the deadline is not met. The agreement does specify that "domestic action plans" are being developed. However, it is the question of what kind of measures they will propose.

4.1.1. Strategies to mitigate the algal blooms

Historically, many different control measures to divert the algal blooms have been mechanical, varying from bio-manipulation, aeration of the lake, liming (a process where limestones alter the pH of the lake, creating a more hostile environment for algal), and dredging to improve water flows. These techniques are incredibly expensive and therefore not resilient, as they do not solve the problem—they are merely attempts at mopping with the tap open [41].

The following strategies are currently existing in the Maumee watershed:

4.1.1.1. Policy

Over the last 2 years, there has been some movement in terms of legislation. The Governor of Ohio (John Kasich) has passed a Farm Bill in 2015 that regulates the application of fertilizer and manure by farmers. The law limits application on snow-covered soil, saturated soil, and when the weather forecast predicts rain within the next 12 h [42].

Another bill that was adopted is Farm Bill 150; it requires all farmers that apply fertilizer to undergo a certification process that educates them in fertilizer application, encourages the adoption of nutrient management plan, and allows the Ohio Department of Agriculture to better track fertilizer distribution [42].

Although the impact of this legislation is hard to measure, it does seem a step in the right direction.

4.1.1.2. Changing behavior

The 4R strategy was put forward by the global fertilizer industry in 2009. The Ohio Department of Agriculture has adopted this strategy and now enforces the training under farm bill 150 [43].

Farmers earn the certification by earning 5 h of education credits. This training is organized by a provider that needs to have at least the level of certified crop advisor. This provider then needs to keep track of the amount of participants and document the progress of these farms in their use of fertilizer [43]. As expected, the strategy involves 4Rs regarding applying manure and fertilizer in the right way (right source, right rate, right time, right place). This is the main strategy that is adopted by the US Department of Agriculture (USDA), the National Resources and Conservation Council (NRCS), and the Ohio Department of Agriculture (ODA) through funding by the Great Lakes Restoration Initiative, a funding mechanism instituted by the federal government, which is the main source of funding for algal bloom mitigation projects instituted by governmental agencies.

4.1.1.3. Green infrastructure and farming practices

There is funding available for farmers who want to take land out of production and use it for strategies such as crop rotations or buffers, two-stage ditches, or other water management installations that will catch the phosphorus before it runs off. Farmers can apply for farm adaptations that will lead to a reduction in nutrient runoff. This is the largest source of funding available and is based on the number of farm acres; it is a set amount of funding each year. It works through a 3–5-year contract that is more likely a mortgage and is competitive. When a farmer applies, they get a technical report from the Soil and Water Conservation District. The farmer then gets a 50–100% match to their own funding proposed. This is a fund that comes from congress and exists until the money is finished [44].

4.1.1.4. Monitoring

Currently, Toledo's drinking water is monitored every 10 min, and people have the option of getting an alert from the water company in case of a threat.

Monitoring also exists in the water surface water bodies going into the lake. The Great Lakes Restoration Initiative differentiates between sensors on different scales in the larger Lake system, the tributaries of the Maumee as well as Edge of field monitoring, which is in collaboration with local farmers. Since there is a lot of skepticism about where the nutrients actually come from, which farmer is contributing and how much, this is a key component. Monitoring is a big part of assessing which strategies could work, as it provides the grounds for a solid impact analysis [45].

4.1.1.5. Technological retrofitting

In the 1980s the municipal governments of the urban centers surrounding Lake Erie pushed back the phosphorus loading levels by implementing retrofits to the wastewater treatment plants. An investment of eight billion dollars was made [46]. Currently, the city is a new phase of retrofitting the drinking water plant [47]. Although there is funding available both governmental and nongovernmental and there is a definite need for systemic change, an integrated response to the algal bloom has yet to be seen. In the summer of 2017, more algal blooms occurred in Lake Erie although the drinking water was safe this time [48].

4.1.1.6. Enaegon's proposal

Enaegon proposed to build of the existing incentive of creating edge-of-field buffers for farmers. Through a productive ditch filter of efficient crops with high phosphorus uptake, the nutrient runoff can be decreased intensively. Participating farmers will profit from the sale of the phosphorus-rich crop. The ditch can be implemented through existing mechanisms such as funding and distribution, enabling a farmer to shift the problem of overfertilization into an economic opportunity. Simultaneously, the relationships between rural and urban populations will be strengthened through documentation. The project entailed an interwoven system design of an environmental strategy, economic strategy, and a social strategy and built of existing funding, monitoring, research, and relationship.

4.1.2. Challenges to systemic change in the Maumee watershed

The complex process of trying to implement this project provided us with many insights into the Lake Erie algal bloom and the barriers to implementing any integral innovation.

4.1.2.1. Skepticism

Farmers are skeptical of their share of the problem. Who is the actual source of the nutrient runoff causing the blooms, is it the Concentrated Animal Feeding Operations or the regular farming operation, and if so, which farmers are to blame? The percentage of farming contribution to the issue of nutrient pollution depends on to which stakeholder you talk too. In terms of advice, farmers take it rather from industry actors such as fertilizer companies and their consultants, instead of the government, e.g., their local soil and water district. Also, Toledo residents are skeptical of the water that comes out of their taps. Since microcystin toxin does color the water. Public cases like Flint, Michigan, further induce governmental mistrust.

4.1.2.2. Monitoring and modeling

When there is a perceived source, you may identify the polluter and hold him responsible, i.e. the polluter pays structure. Monitoring is a timely and expensive manner; only watching

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is and not acting is a problem in the public perception. Although Heidelberg University and other individual researchers are installing edge-of-field monitoring, this practice can be used for impact analysis, but wide implementation for finding out the exact source at this point seems unattainable. Furthermore, using models to predict the flow of nutrients or predict future weather is covered in uncertainty. How do we plan the measures that will also be a fit for future conditions?

4.1.2.3. Funding

Whereas we have identified four main funding sources (the Ohio Sea Grant, EQIP, CRP, and GLRI), there are barriers to these mechanisms. First is the uncertainty of continuation of this funding source; Ohio's department of higher education might stop funding the Ohio Sea Grant, which would decrease research done on this subject. Also, with the change of office in 2017, the Great Lakes Restoration Initiative could very well dry up, taking away funding for projects for local governments. Then there is the question of yield. Farmers are reluctant to adopt because it might affect the yield of their land. We must not forget that farming is a for-profit business.

4.1.2.4. Collaboration and implementation

There are more than 150 stakeholders involved in only the Maumee Watershed. One of the main problems is the fact that commitments have been made on federal and state level, but the actual action, besides policy, needs to be undertaken on micro level, at the level of county or municipal government. Furthermore, conflicting and overlapping administrative boundaries further trouble implementation of meaningful policy. Lack of communication leads to an abundance of reports, covering the same topics, just slightly changing the scope. It is important to notice that an important part of this entanglement lays at the many different types of actors that are trying to work together in different ways and their diverse sets of values and objectives. Finally, it seems that the core issue is the lack of overview of existing incentive and organization.

4.1.2.5. Ownership

Land ownership is a crucial component of this system. Not only is the land fragmented by different types of land use or administrative boundaries but the quantity of owners mostly fragments it. The water that carries the nutrients travels through these different sheds of ownership. One important takeaway is that both ditch and buffer strip are owned and maintained by the farmer but have to meet EPA regulations. However, there are minor parts where county governments have jurisdiction over the ditches and streams.

4.1.2.6. Communication and awareness

There seems to be a serious lack of media coverage. Farmers are not aware of all the progress that has been made by the municipality, and the media is not willing to cover it. In many conversations I had, the fact that farmers will only implement if they know that something will have an impact, seeing is believing. Incentives such as demonstration farms, no-tillage breakfasts, and research demonstration, as well as word of mouth between farmers, cater toward adaptation.

4.1.2.7. Land use

The Maumee Watershed and surrounding areas are overwhelmed by the amount of industrial corn that has been planted, induced by the era of intensification and industrialization. Federal subsidies on mono-crop corn production are maintaining this system, and farmers will take action if the benefits of taking action outweigh the benefits of not taking action. In the long run, changing the system will probably only happen when the intensity of production lowers in the area.

These barriers are specific to the Maumee Watershed, Toledo, and the Lake Erie algal blooms, but thinking of this as a wicked problem, can we place them in a wider context? Which high-level challenges can we define that apply to innovating for systemic change while dealing with a wicked problem?

5. Societal challenges to implementation

Extreme weather events are not disasters; they become social disasters when they affect people [5]. Often the extremity of the consequences of a natural event is caused by deep-rooted societal problematic. There is a lack of integrated responses that link to geo-physical understandings of water systems with political, social, and cultural analyses and vice versa. We try to control the entire earth system to ensure the ecosystem services we need for growth, but society is still dependent on the geophysical processes that are in place. In our attempts to optimize our benefits and resource availability, we alter the cycles that inform our system hydrology (sediment, carbon, nutrient, and water) to our disadvantage. These cycles are what inform the hydrological movements within the geophysical fabric of time and space.

What challenges are at the base of societies' inability to plan for future conditions?

First, hydrological and climate models have increasingly become agents that inform that policy landscape, by putting the spatiotemporal dynamics of the geophysical system into a data model. However, most climate models do not accurately represent risk since they are often based upscaling of scenarios or historical events [49, 50]. Edwards (2003) identifies a scale of force that runs through the human body into the geo-physical sphere. The force of water can only be controlled within a certain range of natural variability. In other words, we cannot plan or predict for forces of strength or character that we have yet to experience and do not understand. As a political issue, climate change represents the dawning awareness that geophysical scales of force must be included in any complete analysis of infrastructure. However, we must realize and account for our limitations in predicting future ecosystem states [51].

Second, every implementation has an investment associated with it. A challenge in implanting large-scale water innovations is that investment cycles of capital are often too short, e.g., a government that is in place for 4 years [52]. Furthermore, governments are often risk averse; they are likely to invest in proven technologies that have guidelines and projections. After all experimentation with new measures can result in catastrophic social implications and loss of economic resources [50]. However, the solution for a wicked problem is not one that has been tested before.

Additionally, which institution is responsible, how are decisions being made, and based on what knowledge are they made? Edwards (2003) points out that multilevel governance slows down the implementation of measures, as different institutions get entangled with each other in decision-making and responsibility. Furthermore, administrative boundaries and the fact that water flows require collaboration between different regimes complicate the response. Watershed borders are different borders than administrative borders [51]. Then, legal control of water resources can be a constraint to innovation (e.g., water supply, permits) [50]. Finally, the political waterscape is largely influenced by the knowledge that is available. There are multiple, sometimes conflicting, disciplines through which water is studied. What scientific practices, infrastructures, and organizations shape water in different places? Several socio-political infrastructures have been built to address water issues such as the Environmental Protection Agency in the USA or the Waterboards in the Netherlands; it is important to consider which knowledge disciplines and actors are included and how these models shape the system (e.g., local knowledge). What historical, social, and cultural factors shape the development and use of scientific research and governance styles? After all, what counts as science and how are these disciplines framed changes through the decades?

Fourth, what are actual innovations and what is re-branding? Green infrastructure is a good example. One of the issues with the urban fabric is the fact that it covers what is underneath, limiting the infiltration of water. In some cities, hard surfaces can account for as much as 84% of the total surface [53]. Andersson et al. ([54], p. 156) define green infrastructure as "an interconnected network of multifunctional green-spaces that are strategically planned and managed to provide a range of ecological, social, and economic benefits." Examples include green roofs, public parks, urban wetlands, green streets, and bioswales [54]. The high-level benefits of green infrastructure are twofold; they regulate stormwater runoff as well as decrease the heat island effect but also allow for recreational benefits [55]. A key challenge regarding the implementation of green infrastructure lays in its perception. How can urban planners utilize green infrastructure to mitigate pressures on the urban ecosystem instead of merely using them to re-brand existing incentive as being "green" [56]?

Finally, although we attempt to shape the geophysical influences in our human time frame, these efforts will in the end not shape the geophysical indefinitely, as the system over millennia will evolve to different states. Current infrastructures on geophysical scale are fragile structures. Although we try to control the geophysical system within an era, we call the Anthropocene, in order to get water to our taps, we still rely on the cycles that make up the geophysical systems. What are scalable solutions, and do these even exist [50]?

So how do we move forward? How can we overcome these wicked problems and create resilient urban centers that will be able to deal with the pressure of climate change and rapid urbanization stake? How can we accomplish real innovation with visible results?

6. Innovating in wicked problems

Wicked problems pose serious challenge to the conventional view on innovation. The convention comprehension of an innovation process starts with the definition of clear ideas for solutions and go-no go decision-making in five subsequent main steps, sometimes subdivided into more. In this view, researchers elaborate on specified issue, and engineers define workable concepts. This research and development phase should deliver inventions. Then, the proof of concept is demonstrated, pilot production starts, and product is commercialized. This business development phase should deliver an innovation. The decisions are made in the selection process, referred to as a funnel. All costs of this process can be covered only if each step is successfully fulfilled; it is if the researchers elaborated on right questions, designers attained a novelty, customer are satisfied with it, pilot delivered sufficient quality, and sales generated profit. This demand-pull model is vested in the public administration and management handbooks [57]. It can reflect processes in large public institutions and corporations but rarely applies to small- and medium-scale businesses and individual experts who usually develop by trial and error using their knowledge and picking ideas available for free. Nevertheless, they are main sources of innovations, particularly when environmental issues are addressed [58]. Since the wicked problems are contextual, they can only be mitigated case by case without claim of applications to many other cases; the demand-pull model is rarely practical in such cases.

A different train of thought is embraced in the entrepreneurial model of innovations. Uncertainty, herewith, is considered a source of entrepreneurial operations and necessary for discoveries. The essential entrepreneurial skill is scanning and finding opportunities for discoveries due to differences in information and understanding between interests. Errors of some decision-makers are resources of innovation for others [59]. The innovating can be comprehended as an individual capability in using knowledge and skills that are available in society for creating new practical solutions. This use of knowledge and skills refers to knowledge spillovers being a metaphor for valuable interactions about the knowledge issues and solutions between people, which can vary from exchange about a cooking receipt to space travels. Although the value of interactions is rarely predictable, the conditions for knowledge spillovers can be fostered through education, cultural diversity, creativity, freedom of expressions, and suchlike, and the entrepreneurial skills in discovering opportunities for innovations can be enhanced through engagement of interests in networks, awarding of outstanding ideas and suchlike social relations [60]. In this view, creating conditions for the knowledge spillover and risk bearing is advocated rather than creating bureaucracy with the aim to reduce uncertainties through more specific selection of innovators, which is close to gambling and deplores innovation. Taleb wrote "Innovation is precisely something that

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gains from uncertainty: and some people sit around and wait for uncertainty and using it as raw material, just as our ancestral hunters" [61]. This notion of unpredictable innovation processes, meanwhile, entered into the mainstream of management theory, referred to as the effectuation theory [62]. Herewith, the entrepreneur is not striving toward a clearly defined goal based on the probabilities of success deliberated with regard to all relevant factors but has a multiple options to choose at a time depending on entrepreneurial personal preferences and given external conditions. Wicked problems, herewith, are tackled based on concepts of possible solutions designed for the specific situations and tested in cooperation with relevant interests. The successful solutions can be adapted and applied in other contexts. This trial-and-error process evolves when broad knowledge basis can be used.

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