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Robots in drinking water: A pipe dream?

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Abstract

This study addresses the regulatory impacts on an innovative project seeking to introduce autonomous robots into the potable water network, Pipebots. It does so through the lens of adaptive governance, principally the under-explored area of adaptive governance and formal law. Through this study, suggestions are made to improve the regulatory regime, including a separate authorisation process for novel or complex products, built-in feedback loops to encourage learning and reflection and the need for early engagement by innovators in the regulatory process. Further, the analysis exposes a wider, serious tension: How do we encourage the innovation and flexibility we need to ensure the resilience and sustainability of our systems and at the same time safeguard strict human and environmental protections? The Pipebots project is used to explore the law's role within adaptive governance, and suggestions to improve water governance are proposed.

Impact statement

This study explores the tension between existing law that seeks to protect potable water quality, and new policies requiring innovation and flexibility to preserve our water supply. As we face the climate and water crisis, resolving this tension is arguably one of the most significant challenges of our age. Through the eyes of a new innovative project, the existing law in relation to potable water is explored and the challenges it gives to innovators is exposed. The findings suggest existing legislation has too narrow and restrictive a focus and recommendations are made for improvements that seek to balance trust, quality and sustainable supply. Although English legislation is studied, the provisions and principles are drawn from EU law and the issues likely to be common across many jurisdictions.

Introduction

Water is a life-essential resource under stress and how to value and govern it is a global challenge (OECD, 2015; Ahlström et al., 2021). Reducing the amount of water wasted through leakage is a key governance challenge to ensure the resilience of the water supply system and to reduce stress on the environment (Ofwat, 2022). With many of the easy wins in terms of leakage detection already identified, innovative new science and technologies are sought to meet governance targets while ensuring that existing, stringent water quality regulations are not breached.

Science and engineering are rising to the challenge, and innovative projects are being developed. Pipebots is one such project that seeks to meet the leakage challenge by mapping the potable water supply networks and identifying existing leaks (before they manifest into bursts), points of incipient leakage and areas of vulnerability. The Pipebots project seeks to revolutionise buried pipe infrastructure management using swarms of micro-robots that will 'live' in and periodically scan the entire pipe network (Pipebots, 2022). They will carry sensors to gather data on the condition of the pipeline system and the surrounding environment, and how well it is operating and/or responding to fluctuations in pressure. Unlike existing mainstream systems, they will be autonomous and untethered, sensing and adapting to changes in its environment for extended periods of time.

The Water Supply (Water Quality) Regulations, 2016, as amended, (referred to as the *Regulations*) is a Statutory Instrument providing the regulatory framework for the drinking water quality of the public supply in England and is enforced by the Drinking Water Inspectorate (DWI: Water Supply (Water Quality) Regulations, 2016). The *Regulations* govern drinking water quality in the public supply system in England up to point of delivery to premises. Although applicable to England similar principles, originally derived from EU law, apply in other jurisdictions.[1] Pipebots must be granted prior approval under Regulation 31 of the *Regulations* before they are introduced

[1]The *Regulations* are a Statutory Instrument that seeks to implement the statutory duties set out in its enabling statute, The Water Industry Act 1991 (as amended) (Water Industry Act, 1991), which in turn implemented the European Drinking Water Directive 98/83/EC (Council of the European Union, 1998) into English law.

into the potable water network. They constitute a niche set of regulations that focus on the safety of the potable water supply insofar as public health is concerned. Regulation 31 addresses what substances and products can and cannot be introduced into the water supply and provides the framework for an approval process for new substances and products.

While policy and necessity may be driving innovation in the potable water sector, the issue explored here is whether pre-existing legal regimes are supporting or blocking innovation, and if so, how those legal regimes can be adapted to allow for needed change while maintaining standards. Pipebots offers a tangible opportunity to explore tensions between innovation, stimulated by policy goals, and an existing, strict regulatory regime.

This study introduces Pipebots and Regulation 31 in Section 2. In Section 3, the academic and regulatory context are discussed, drawing out the principles from the adaptive governance literature and specifically how these can be used in evaluating law. Section 4 brings Sections 2 and 3 together by applying adaptive governance principles to the *Regulations* using Pipebots as the context. The results are analysed in Section 5 with a wider discussion on the impacts of the regulatory regime in Section 6. The conclusion proposes a way forward in terms of both the *Regulations* – specifically how they might be refined to accommodate novel technological developments and the wider (inter) national imperatives of sustainability and resilience – and the design of research and development projects to realise these new technologies.

Pipebots and regulation 31

The Pipebots project is currently in Technology Readiness Level 1–3 and therefore the components and their materials are yet to be settled upon. It will, however, require a power source, moving parts for navigation and (possibly multiple) sensing capabilities. The Pipebots must be safe in terms of their effect on potable water and their interaction with the network. The Pipebots will have to meet those safety standards and obtain prior approval under Regulation 31 before they can be put into operation.

Regulation 31 overview

Under the provisions of Regulation 31(1), a water undertaker must not introduce a substance or product into the water supply unless conditions are satisfied. To introduce a Pipebot would therefore be in default unless it falls into one of the exceptions listed.

The exceptions under Regulation 31 are included in Sections 2 and 4 of the regulation. Section 2 covers the case in which the product already has an appropriate British Standard or equivalent approval, that is, has already undergone a suitable, recognised testing process. As a Pipebot has not yet been pre-authorised with a BS EN mark or equivalent, Section 4 provides for three alternative options for compliance:

a) To seek product approval under a scheme authorised by the Secretary of State (*the full, formal application process)*;
b) Where the product is such that the Secretary of State considers it is unlikely to affect water quality (*is of a pre-ordained type of product that has been deemed safe*); or
c) Where the product is introduced for a limited and controlled period for the purposes of testing and research (*a limited research and development type application*).

Option c) does not provide for permanent authorisation. Option b) has limited application (but for completion, an analysis is included in Supplementary Appendix 1). The focus is therefore on a).

The DWI operates the approval system on behalf of the English and Welsh authorities (DWI, 2022a) and has created detailed advice sheets setting out its processes. The provisions of Regulation 31 are elaborated upon and operationalised in the advice sheets and need to be considered by project teams.

Option regulation 31(4)(a): Full application process

Regulation 31(4)(a) approval follows the DWI formal application and testing process. The process is set out in Advice Sheet 1 (DWI, 2023). Section 3 of Advice Sheet 1 sets out the need for full disclosure of formulation details for the product and all individual ingredients, usually a BS6290 test report and details of the quality management system for manufacture and supplier. The process can be abridged, for example, in some circumstances if it is of a recognised grade of material. The status quo is arguably underpinned by a preference for pre-ordained components. Pragmatically, a project design team aware of this list may be well advised to consider using components that have already tested and approved, if possible to do so.

'In contact' with water and instructions for use

The number of component parts in a moving, autonomous robot with sensors and communication abilities will likely be substantial. However, not all of these will be in contact with the water, being enclosed in a sealed unit. Unfortunately, whether they still need testing is not clear. Regulation 31 does not appear to use the terminology 'in contact', although the originating Directive does, as is the case for Advice Sheet 1:

> "This Advice Sheet deals with the approval system for substances and products and used in contact with public water supplies in the UK". (DWI, 2023).

How 'in contact' will be determined is not immediately clear. The power source *via* a battery, for example, is unlikely to be considered inert, albeit may be small in concentration, and not in contact with water unless the robot becomes damaged. It is assumed that the answer may depend upon use and how long the robot is *in situ*; the risk of contact being small if the product is in water for a very short period, for example? In support of this assumption is the Instructions For Use (IFU). A key part of the approval process is the provision of an IFU document described in Advice Sheet 2 (DWI, 2024). This describes how the product will be used, with safety and risk being assessed accordingly. Following this reasoning, how long a Pipebot will be intended to be in contact with water could be a key part of the IFU, which in turn may determine issues around decomposition, damage and leaching and so risk. In designing the technology, a clear view on how it will be integrated and used operationally is therefore needed – before approval is sought so the risk can be assessed. Even then whether each component will still need full approval, whether in contact with water or not, is unclear from the Advice Sheet.

Post approval changes

Further, the approval does not last indefinitely: it currently lasts for 5 years (DWI, 2023), and if the IFU (or the product) changes during that time further Regulation 31 approval may be necessary. Indeed, out of the 137 changes to approved products recorded in an annual product list review published by the DWI, 111 related to IFU

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changes (DWI, 2021b, 2021c). To put this number into context, only 25 new products were added to the list, and six refusals were issued over the same period (DWI, 2021b, 2021c). This has repercussions for a multi-component robot where if, in its use, a component (or its manufacture) changes it will likely require new (or amended) approval on each occasion.

Opportunity for process improvements or challenge?

Clearly, the approval process is not intended to be taken lightly and we are, after all, talking about the safety of potable water. Those working in innovation in the sector with whom the Pipebots project have engaged anecdotally described Regulation 31 as being a costly, work-intensive and time-consuming process (with pre-application work described in years not months) with lengthy backlogs. While undertaking interviews with experienced innovators in the sector one participant simply described it as a '*nightmare*', with the situation even more labyrinthine for those seeking to engage with the sector from outside. This begs the question whether the process could be better. Documentary details on the efficiency and running of the regulatory process are sparse and could not be located at the time of writing – and may not be available due to commercial sensitivity (the protection of commercially sensitive data being a significant concern in a market-based regime). This may explain why the reason for six products being refused is not known and why the length of the process was not discernible.

It does not appear that the process itself has been substantially reviewed or amended. The process is not set out in a statute, so amendments are more difficult to track and interrogate; however, anecdotal comments from the sector suggest there has been no change and the founding *Regulations* themselves, although dated 2016, do not appear to have been substantially amended, so far as the relevant provisions are concerned, from the earlier 2000 version (Water Supply (Water Quality) Regulations, 2000). There is also the question of challenge and learning (in keeping with adaptive governance discussed in Section 3). How feedback and learning from experiences of the process are managed and disseminated, if at all, is not made clear. It suggests the only challenge process may be *via* formal legal mechanisms or a generalised complaints process.

Project impacts

Any issues are likely to be more acute with new, transformative, multi-component engineering simply because of the variables and new components to be assessed. The problem is evident in the advice sheets themselves. The advice sheets refer to the types of products they will consider – such as treatment chemicals, pipes and repair materials, for example – so the hard infrastructure and the treatment processes (DWI, 2023). The logical conclusion is the authorisation process appears designed for the assessment of simple constituent components, chemicals for dosing or materials used in permanent fixtures such as tanks and pipework, for example, rather than complex, multi-component robots. Indeed, the DWI advice sheet itself notes a meeting may be necessary in cases of more complex components, appearing to recognise the issue (DWI, 2023), albeit there is no alternative process evident.

Regulatory impacts

The above, not unexpectedly, suggests the processes have been designed for traditional types of water infrastructure with a preference for pre-ordained products, not improvements. While it is understandable that mainstream processes will initially be designed to accommodate traditional component types, without feedback loops, review and reflection mechanisms, there is a potential for both lock-in and obstacles to more innovative products or system changes.

Literature: Academic and regulatory context

It is arguable that water governance has been more successful in relation to drinking water quality than with wider water cycle management, certainly in England. In contrast to concerns over the quality of the water in the UK's rivers and oceans (Surfers Against Sewage, 2022; The Rivers Trust, 2021; The Wildlife Trusts, 2021), drinking water in the UK is consistently deemed to be of a very high standard (DEFRA, 2021). In this respect the *Regulations* could be considered a success, but this does not consider how the *Regulations* respond to innovation seeking to tackle pressing water system problems such as leakage. In evaluating the *Regulations*, principles from the adaptive governance and socio-ecological system (SES) literature can be utilised. Principles of adaptive governance are drawn upon because they offer insights into good governance of natural resources, particularly in resilience-building for times of unpredictability and stress (Dietz et al., 2003; Walker et al., 2004; Chaffin et al., 2014). Adaptive governance emerges from SES studies on environmental governance to address the uncertainty generated through issues such as climate change (Pahl-Wostl, 2009). Rather than expecting certainty or seeking optimisation within a changing system, adaptive governance seeks resilience through learning, flexibility and adaptability, thereby enabling transformation (Walker et al., 2004). It is governance for resilience that learns and adapts rather than locks-in systems and resists change.

Learning and flexibility are key components of adaptive governance. Pahl-Wostl (2009) explores the concept of triple-loop learning for adaptive capacity in resource governance and her work strikes a note here, particularly her drawing on the work of Flood and Room (Flood and Romm, 1996). In brief, single-loop learning is described in terms of learning through incremental change without challenging underlying assumptions (sometimes noted as 'doing it right'), double-loop learning is said to re-visit assumptions ('doing the right thing') with triple-loop learning going further and tackling underlying values and the frame of reference (Flood and Romm, 1996; Pahl-Wostl, 2009). That approach may be beneficial here. The issues are not only at the incremental process level (adapting for novelty), but deeper around the underlying assumptions and values about drinking water quality and innovation.

Formal law, a tool of governance, may appear in direct conflict with learning and adaptive governance, and even a barrier to its application due to its preference for stability over flexibility (Cosens et al., 2020). Formal legal systems are traditionally considered to have strength in providing that certainty, due process, enforceability and security. Indeed, regulatory stability and certainty is considered necessary to attract investors; essential in a privatised system (Dept of Business Innovation and Skills, 2011). In the case of potable water infrastructure, arguably elements of both are required; the strength and certainty of formal laws to safeguard potable water with the adaptability of a governance system that is flexible enough to enable transformational system changes through innovation for the resilience and sustainability of the system.

Although there is an extensive body of work around adaptive governance and informal rules and norms, there is considerably less around the role of formal law, and its potential has been overlooked (DeCaro et al., 2017; Garmestani et al., 2019). There is a conundrum of how law can be strong and certain yet flex and adapt, coupled with few studies supporting evaluation of regulation in this area.

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Drawing on existing insights, the study by Hill Clarvis et al. (2014) suggests four guiding principles for a legal system seeking to support system resilience – *iterativity, flexibility, connectivity* (including networks across scales and sectors for collaboration) and *subsidiarity* (implementing rules at the lowest or most suitable level) – all showing elements of learning, acting upon what is learnt and inclusion of stakeholders at all levels. Taking this further, DeCaro et al. (2017) embrace adaptive governance and law, and suggest adaptive governance principles for the design or evaluation of law directly. It is based on a body of work developed in the United States (and notably much of the work in this area is of US origin (Frohlich et al., 2018) although, as a common law jurisdiction, the principles may offer insights into how this is interpreted in an English legal context. The principles include whether there are periods of evaluation (termed *legal sunsets*) and the degree of flexibility (termed *reflexive)* where needed (DeCaro et al., 2017). These suggested adaptive governance principles can be used to evaluate formal legal regimes.

Evaluating regulation 31

In evaluating Regulation 31, principles of reflexivity and legal sunsets can be drawn upon (DeCaro et al., 2017).

Reflexivity

Reflexivity is a call for the avoidance of static rules when flexibility is required, or phrased another way, for the establishment of standards but also space for creative solutions to meet those standards (DeCaro et al., 2017).

There is a degree of inbuilt reflexivity potential in how the rules are structured. There are tiers of rule-making with overarching principles that are fixed at the top, *via* Acts of Parliament, with details for implementation and processes at lower tiers, the latter being more flexible and easier to update. In theory, the legal requirements of the Directive and Act effectively define the free operating space for the *Regulations* and Advice Sheets. One can see how this has the potential to be both strong in terms of public health (e.g., laying down enforced principles at a high level) and flexible in terms of how it is achieved (*via* appropriate authorisation processes that can be updated).

A question arises as to whether this structure translates to reflexivity in practice, as seen through the eyes of the Pipebots project. Tracking the changes to the Regulations, it does not appear that the authorisation process has been substantially updated for more than 20 years and does not appear to have been designed with disruptive technology in mind; if there is a review process, this is not immediately evident to a project team outside the sector seeking to navigate the complex rules.

As discussed, feedback and learning are key components of complex systems and its adaptive capacity (Pahl-Wostl, 2009; Chaffin et al., 2014). Without a clear review or challenge mechanism, the benefits of a reflexive structure may be lost. If there is no accessible review, the need for adaptation and change to allow for innovation is not identified. Overall, it becomes a fixed, static system rather than a responsive and adaptable one.

Legal sunsets (DWI, 2018b)

Legal sunsets are described as planned periods of reflection and evaluation in which the governance system can be re-examined and modified as required (DeCaro et al., 2017).

The regime controls water quality through extensive lists of defined parameters, products and substances. Under the originating Directive, water safety parameters were designed to be reviewed at least every 5 years in the light of 'scientific and technical progress' (Council of the European Union, 1998).[2] The lists were never designed to be static, and have reviews built in to adjust to scientific knowledge. It is an example of integration between law and science. In this respect, the rules are reviewed and can flex and adapt as new science-backed evidence arises about the safety of contaminants in water. This form of rulemaking has the benefit of being clear and supported by robust evidence. It is also easier to enforce at the appropriate time and level, a key requisite of a regime of this nature (Hill Clarvis et al., 2014); testing for discrete substance levels in water is an easier parameter to understand, and to be measured and judged against, than the looser concept of providing 'safe' water.

However, there are consequences. It appears more likely that as science progresses, or the precautionary principle is triggered, the list of controls will get longer and tighter; microplastics (WHO, 2019) and antibiotics (Soler, 2019), being notable possibilities. Safety margins are described as 'wide' (DWI, 2018b). With wide safety margins and expanding lists, the operating space appears more likely to contract than expand with more tests and requirements and increasing, not decreasing, length and complexity.

At one level, in terms of the defined parameters and the narrow goals of the regime, there are planned periods of reflection and evaluation. However, that reflection and evaluation is limited and does not ask deeper questions about the consequences of those reviews or whether there should be reflection upon the regime as a whole. This suggests that the reflection is limited and not in line with thinking around triple-loop learning.

Analysis: Regulatory design

The application of the adaptive governance principles, presented in Section 4, suggests that there are elements of alignment with adaptive governance. However, the *Regulations* are designed to control risk in relation to the narrow parameters of potable water safety. They can be viewed as less flexible and adaptive when the wider governance regime and needs are considered:

The extent the Regulations are designed for innovation, complexity or system change

Issues of uncertainty over the application of the *Regulations* have been flagged (e.g., 'in contact' with water, complex components and surface area calculation). Uncertainty is unhelpful when seeking to innovate. Furthermore, there is the fixed and static nature of the approval process. It is governance that has been designed for a specific purpose around risk, not governance that is designed to stimulate the process of systemic change for sustainability.

The Regulations are an 'end-of-pipe' solution

In considering legal sunsets, the problems of expanding lists of parameters and consequent complexity were noted. It can be argued that this complexity arises from systemic problems and silos in water management, not the *Regulations.* The *Regulations* have to respond to the quality of the water abstracted and 'new' risks (e.g.,

[2]Noting the EU Directive has since been amended, the change in regime is not addressed here.

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microplastics), and this, in turn, is impacted by how wastewater and drainage are managed; the more contaminants in the water cycle, the more that has to be removed in the processing. The combined effects of low-quality water bodies, increasing contaminants (or knowledge and perceptions around contaminants) and water stress are arguably increasing pressures at the end of the cycle when water is abstracted to be processed for drinking (Milman et al., 2021).

In this way, the *Regulations* are a legal 'end-of-pipe' solution, mopping up the issues generated by the condition and contaminants in the water bodies from which the water is abstracted. As with technical end-of-pipe solutions, this does not address the systemic issues within the water cycle. Instead, it is argued that problems with water processing are multi-faceted and need to be addressed systematically rather than leaving this to contaminant removal at the drinking end of the cycle (Rogers et al., 2020). This is an issue of problem framing. Rather than contaminant removal or drinking water quality (and end-of-pipe solutions), the problem could be more widely drawn as an issue of water cycle management, thus requiring integration with regulatory solutions that address systemic issues and prevent contamination.

Discussion

The analysis highlights how regulation shapes the space for innovation to take place and provides limits on what acceptable outcomes might be. Potable water requires protection; the issue is how best to achieve that without stifling change that may determine the degree water is available at all, and at what cost. The application of the adaptive governance principles against the *Regulations* provides insights, but wider issues behind the *Regulations* start to become evident and leave openings for a wider discussion and healthy debate.

This introduces the question of what regulation in the sector should be for: should it simply be a mechanism to restrict what is done to protect one or more specific characteristics of society (e.g., public health) or should it be framed in terms of an opportunity to enhance social, environmental and economic performance (in this case, of the water industry), bring resilience to the systems of operation and help to meet the wider national and international priorities, such as the UN Sustainable Development Goals (United Nations, 2023)? The framing and purpose of legislation would be subtly different and perhaps more readily support mechanisms for system change.

There are also the consequences of the separation of the drinking water governance regime from the rest of the water management cycle. Drinking water is not simply a technological issue of quality. It reflects societal and political choices that impact on the well-being of people and the wider environment through principles of social and environmental justice (Shrimpton et al., 2021; Bowman et al., 2022). There seems artificiality in rules that address only sections of a water cycle. That water needs to be managed holistically is a matter acknowledged in the Sustainable Development Goals (SDGs) (United Nations, 2023) and accepted in governance mechanisms such as the Water Framework Directive (European Parliament and Council Regulation (EU), 2000). Indeed, the connectivity of drinking water quality and the need for sustainability is recognised by the DWI itself in its own recent guidance note on resilience, although noting its own lack of statutory duty (and so arguably a clear role) in the development of Water Resource Management Plans (DWI, 2021a). The results are uncertainty and complexity for a project team, even though that team seeks to address other aspects of water governance, and inertia in terms of needed system change.

It is not the Regulatory drafting that is necessarily an issue then, but its scope; trying to manage a discrete part of the water cycle in isolation. Leakage reduction targets are also governance targets, albeit under the auspices of Ofwat[3]; the position in relation to the environment is also serious and requires action. There is the wider issue of reflection, not against the defined goals of the *Regulations* but against the needs of the governance of the hydro-social water cycle.

The issue around managing risk, perception of risk, innovation and public health is a highly problematic one, if not a Holy Grail. Only imperfect solutions for wicked problems may exist (Marchant, 2020). The principles of adaptive governance, particularly around reflection and learning, may provide the best opportunity for a solution – albeit an inevitably imperfect one. With this in mind, the following suggestions are made:

Process adaptability for innovative products

The Pipebots case study suggests a new or adapted process for innovative projects and systemic change is required – designed in consultation with stakeholders in the sector. This maintains a degree of status quo yet provides alternative processes for innovative products. Examples of more flexible processes in special cases already exist, such as a move from a single application process at the end of development, to a staged or work-in-progress model using regulatory gateways for input during design and development. Even regulatory processes that are designed to provide the most stringent safeguards for trust and public health can adapt. This was seen in the recent pandemic by securing vaccine approval using the rolling review process (UK Gov, 2020) and seen in the use of regulatory sandboxes[4] (e.g., Ofwat, 2019; Ofgem, 2024) Regulatory sandboxes could be explored in conjunction with part c) of Regulation 31, which allows for technical trials, for example.

To be clear, these suggestions can be brought about with mechanisms in place to manage risk. This is not about reducing necessary protections.

In-built (triple-loop) learning

When applying the adaptive governance principles, there were elements of single-loop learning and adaptation, for example, by updating the list of parameters the regulation controlled. The *Regulations* may benefit from the application of the third loop of review and learning. This could be explored further with a view to better integrate drinking water quality with wider international goals of resilience and sustainability.

Holistic ecosystem governance

The need for holistic governance of the water cycle is already recognised (Ahlström et al., 2021; Dasgupta, 2021; European Parliament and Council Regulation (EU), 2000; United Nations, 2023). This is also recognised by the regulators themselves, for example, through initiatives such as Regulators' Alliance for Progressing Infrastructure Development and innovation hubs (Ofwat, 2019;

[3]Ofwat is shorthand for 'The Water Service Regulation Authority', the economic regulator for water and sewerage sectors in England and Wales (Ofwat:, 2024).

[4]A 'regulatory sandbox' is described by the Financial Conduct Authority as: *'a 'safe space' in which businesses can test innovative products, services, business models and delivery mechanisms without immediately incurring all the normal regulatory consequences of engaging in the activity in question'* (Financial Conduct Authority, 2015, p. 2).

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DWI, 2021a).[5] However, this does not address the legal design and how existing regulations can embed siloed thinking, particularly around the emotive subject of potable water. The case study supports calls to move away from niche regulation that does not take cognisance of other governance challenges and in line with triple-loop learning (Tosey et al., 2012).

To draw the analysis and discussion together, the following themes emerge:

1. The *Regulations* are not designed to encourage innovation or system change.
2. However, the process could be adapted, not necessarily for mainstream products but for products considered more complex, innovative and/or which address wider governance challenges.
3. At a process level, clearer processes for feedback, challenge and learning could be included and encouraged, including allowance for the Regulator to gather data from and provide data to those seeking to navigate the system. While this remains a market-based regime, its mechanisms to safeguard property rights and commercially sensitive data would need to be maintained.
4. Those innovators seeking to bring about change would be well advised to engage with the detail of the legal regime at an early stage and to engage with those experienced in the sector, including regulators.

More widely:

1. A reflection on the founding principles behind the *Regulations* and processes is recommended, not just at a granular level but with triple-loop learning principles in mind, challenging the difficult presumptions such as the use, quality and availability of potable water.
2. A holistic, not siloed, approach to the drafting of ecosystem governance is suggested to address systemic issues – a move away from drinking water regulation as an end-of-pipe solution.

Conclusion

Using the Pipebots project and adaptive governance as a lens, exposes areas of potential improvement in the regulatory regime that can support the innovation needed within potable water systems while maintaining safety. It is proposed that a separate process for novel or complex products is considered. This could be a process with increased touchpoints between regulator and innovator, sandbox mechanisms and staging or gateways through the approval process. Review and reflection built-in to the process are also suggested, providing feedback and even challenge mechanisms for innovators to encourage a process that adapts and learns. Early engagement by innovators with the *Regulations* is also strongly recommended. The *Regulations* are detailed and, while complicated, also offer guidance on what is going to be required for the innovation team from documents such as the IFU through to opportunities to abridge the process with surface area exceptions or approved product lists. It is worth understanding these requirements even in the early design stages to ensure easier routes to regulatory compliance are not missed.

More widely, the *Regulations* can be considered a success in terms of their defence of drinking water quality in England. This is exactly what they were designed to achieve – and ironically, therein lies the problem. Drinking water quality provides a narrow field of vision against the wider context of governance for sustainability and resilience of water management and national and international agendas. There is a need to think differently and not defensively. The need for system change and technological innovation to meet those wider governance challenges is accepted through national and international goals, but Regulation 31 is not designed to do its part in meeting those challenges. There is no clear mechanism for systemic change or technological innovation; instead, there is a complex set of rules and barriers that are unlikely to be well understood outside those regularly operating in the sector, and which encourage the maintenance of the status quo. The consequence of the choices behind Regulation 31 is a narrow operating space for change or challenge. This is not a call for drinking water that is less 'safe', rather a call for integrated water cycle management and innovation. While sections of the legal regime continue to be syphoned off, effective management of the water cycle as a whole is a pipe dream.

[5]It is of note, however, that the Streamline service intended as a one-stop shop for innovators seeking advice from Ofwat, DWI and the Environment Agency expressly excludes advice on Regulation 31 (DWI, 2022b).

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