Information systems, sociomaterial practices and the emergence of environmental management infrastructures

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Abstract

Information systems are an integral part of environmental management infrastructures – complex assemblages of social and technical artifacts, human actors and sociomaterial routines enacted in the pursuit of environmental sustainability outcomes. We analyse the case of an environmental management infrastructure developed around a 'vessel management system' by a South Australian regulator between 2004 and 2013. The goal of this infrastructure was to sustain water quality by controlling the discharge of 'greywater' from vessels on South Australia's inland waters. We conceptualise environmental management infrastructure, and the information systems they encompass, as the temporally emergent outcome of human agents' attempts to extend their environmental management practice in a particular direction, and how that trajectory of emergence is shaped by the intersection of human agencies, material performances and disciplinary practices.

Keywords: Environmental management, information systems, infrastructure, artifacts, routines, sociomaterial practice, mangle of practice, emergence.

1 Introduction

In this paper, we are concerned with how information systems become implicated in addressing environmental sustainability challenges and transformations (Elliot & Webster, 2017; Seidel et al., 2013). Specifically, we are interested in the ways that information systems underpin and coordinate environmental management practice. To articulate our understanding of how change in environmental management practice occurs and the role that information systems play we utilise the concept of 'infrastructure' (Edwards et al., 2009; Star, 1999) and its development.

Infrastructures are complex, extended assemblages of heterogeneous entities (Jensen & Morita, 2015; Venters et al., 2014) that involve "interdependence, intricacy, and interweaving of people, systems, and processes" (Ciborra & Hanseth, 2000, p. 2). Rather than simply being the material substrate that underlies social action such as environmental management (Jensen & Morita, 2017), infrastructure is how the world is made and brought into being – it is the product of co-evolving relations of people, technologies, materials, and organised practices (Harvey et al., 2017; Jensen, 2015; Jensen & Morita, 2015; Star, 1999). Infrastructures are thus open-ended and emergent (Jensen & Morita, 2017), "always an unfinished work in progress" (Edwards et al. 2009, p. 365).

From this understanding, information systems are not standalone entities but contribute to environmental sustainability as part of the social and material relations that form the infrastructure underpinning environmental management practice. The key research question we ask is: How is change in environmental management practice achieved through the development of an environmental management infrastructure?

To address this question, we focus on an example of the environmental management of wastewater – liquid and solid wastes mixed with water as the medium in which they are transported. Environmental stresses related to water scarcity and deteriorating water quality in various parts of the world have focused governmental and regulatory attention on wastewater as an environmental problem (United Nations, 2018). In the domestic context, wastewater includes both waste from toilets ('blackwater') and wastewater from household baths, showers, hand basins, washing machines, sinks or other kitchen appliances ('greywater'). Our case study examines the efforts of a South Australian regulator, the Environment Protection Authority (EPA) to change the way that greywater produced by vessels using the State's rivers and lakes was handled.

To analyse the environmental management infrastructure that emerged in response to the EPA's attempt to manage vessel greywater in South Australia, we adopt a 'sociomaterial' perspective, which helps us understand the complex and dynamic entanglement of human agency and material performances in environmental management practice (Orlikowski, 2005, 2007; Venters et al., 2014). In particular, we draw on Pickering's (1995) conception of the 'mangle of practice' to explain how environmental management infrastructures emerge "through a process of tuning where human and material agencies continually resist and accommodate each other" (Baygi et al., 2021). Our findings offer insights into how information systems underpinning these infrastructures become entangled with other artifacts and work practices and, in the process, transform environmental governance.

The remainder of the paper is structured as follows. In the next section, we discuss the theoretical perspective underpinning our study and conceptualise the emergence of environmental management infrastructure. In the subsequent section we briefly outline the background to the case before discussing how we collected and analysed our data. In the next part of the paper, we present our findings and analysis, before concluding with a discussion of our key findings and contributions.

2 Theoretical Perspective

2.1 The mangle of practice

For Pickering (1995, 2013), human practice is about doing things in a material world. He approaches this from a performative perspective, an "ontology of becoming" (Pickering, 2008, p. 3), in which practice is open-ended and emerges from the interplay of both human and material agencies. If agency is defined in terms of performance rather than intention, then while humans do things in the world, clearly so too do a whole range of nonhuman entities, including material artifacts such as information technology. Both have agency in the sense of performing actions. Pickering (1995) calls this "performative, emergent dance of agency … between the human and the non-human" (Pickering, 2013, p. 33) the 'mangle of practice'.

Nonetheless, human agency is bound with intentionality. Pickering (1995, p. 18) argues that human agents "construct goals that refer to presently non-existent future states and then seek to bring them about". These goals "are imaginatively transformed versions of [the] present" (Pickering, 1995, p. 19). In accomplishing their goals, human agents "maneuver in a field of material agency" (p. 7), engaging and negotiating with an array of material performativities, often through the construction of technologies – "human activities and technological doings" (Orlikowski, 2005, p. 185). Pickering (1995, p. 22) presents this process as a "dialectic of resistance and accommodation": a sequence of temporarily emergent resistances to attempts to capture material agencies in practice – a "block on the path to some goal" (Pickering, 1995, p. 39), and contingently formulated accommodations – an "active human strategy of response to resistance" (Pickering, 1995, p. 22). These accommodations can involve not just revisions to the material form of technologies but also to the contours of human agency and the social relations that encompass it. Thus, both material and human agency (including plans and goals) are mangled and emergently transformed in practice (Pickering, 1995).

In our analysis of the emergence of an environmental management infrastructure for the control of greywater produced by vessels on South Australian waterways we build on the mangle of practice to conceptualise the extension of environmental management practice to vessel greywater management. Detailed reviews of environmental or 'green' information systems research can be found in Singh & Sahu (2020) and Jenkin et al., (2011).

2.2 The extension of practice

For Pickering (1995), new practice is produced from the intentional extension of existing practice in a particular direction. Available resources and agencies are harnessed to create imagined future states through present action (Pickering, 1995, Venters et al., 2014). This process is shaped by existing technologies and the cultural context in which it is situated, which act as the 'surface of emergence' for the new practice (Chae & Poole, 2005; Pickering, 1995). Pickering (1995) suggests that certain elements of existing practice that have become established as accepted ways of thinking and exert a form of agency that disciplines human activities. This "disciplinary agency" (Pickering, 1995, p. 29) shapes human action by providing a repertoire of concepts, conventions, values and procedures encapsulated in particular bodies of knowledge: "the agency of a discipline … leads people through a series of actions and also naturalizes these actions for them" (Chae & Poole, 2005, p. 21). Arguably, disciplinary agency reduces discretionary human agency because it creates inertia when human agents confront existing forms of knowledge and institutionalised methods of action (Johnston et al., 2016; Venters et al., 2014). Thus, the extension of practice at least partially involves the copying of established elements or moves from existing practice.

The attempted extension to a practice involves "the production of associations, the making of connections, and the creation of alignments between disparate [social and material] elements" (Pickering, 1995, p. 139). However, because the outcome of this attempt cannot be known in advance, the various elements assembled do not necessarily perform together as intended. In the consequent struggles between human goals and plans and material and disciplinary agencies, conceptual structures, the material form of technologies, and the scale and social relations of human agency are all mangled in practice. Mangling occurs until "specific trajectories come to be marked out and [interactively] stabilized by the achievement of associations between these elements" (Pickering, 1995, p. 91). In this way, the contours of practice are defined in real time by the emergence of resistances at the intersection of human, material and disciplinary agency, and the success or failure of accommodations to those resistances.

2.3 Artifacts and routines

To operationalise Pickering's extension of practice in our analysis of the emergence of infrastructure, we utilise the concepts of artifacts and routines as the observable and traceable outlines of the exercise of material and human agencies in sociomaterial practices (Gaskin et al., 2014; Leonardi, 2011). Artifacts are material things constructed or produced by a human agent to achieve a given purpose or practical function (Baker, 2004; Verbeek & Vermaas, 2009). Technical artifacts, whether physical or digital objects (Faulkner & Runde, 2019; Leonardi, 2010), perform their function on the basis of their designed form or structure (Kallinikos, 2012; Kroes, 2010). In contrast, social artifacts, such as scientific reports, technical standards, laws and contracts, perform their function "on the basis of collective intentionality" (Kroes, 2010, p. 57) – the collective acceptance of the constitutive rules or norms associated with their status and function (Burazin, 2019) that produces standardised social behaviour (Kallinikos, 2012). Thus, the material agency of a contract, for example, derives not from its inscription in paper or digital documents, but from its use within a collectively recognised legal regime, which serves particular material ends in the governance of human transactions (M. C. Suchman, 2003).

Both technical and social artifacts are constructed in the course of infrastructural development in order "to achieve an intended capture of agency" (Pickering, 1995, p. 22) through their performativity (Leonardi, 2010). These artifacts are incorporated into sociomaterial routines or regular sequences of activities on which human agents rely in their everyday work (Gaskin et al., 2014; Pickering, 1995). We refer to such work practices as routines to distinguish them from practice in the more generic sense used by Pickering (1995). Artifacts lie at the centre of routines – shaping their emergence, encouraging their persistence, guiding the course of action, and performing key functions (D'Adderio, 2011; Pentland & Feldman, 2008). In enacting sociomaterial routines, human agents interact with a range of artifacts, the agencies of which rely on their incorporation and use in specific sites and "skilled practices that bring them into alignment" (L. Suchman, 2007, p. 269).

The artifacts and routines that comprise an infrastructure (Ciborra & Hanseth, 2000; Leonardi, 2011) represent malleable human-artifact relations (L. Suchman, 2007) with varying consequences. For example, artifacts incorporated into a routine may fail to perform as intended. Equally, the enactment of routines may produce outcomes that are inconsistent with the goals involved in transforming practice. Human agents respond by reconfiguring artifacts and adjusting routines, or by creating new ones, as an infrastructure emerges over time. Artifacts and routines thus co-evolve through their involvement in performative struggles among competing agencies (D'Adderio, 2011).

2.4 Synthesis

Our conceptualisation of the emergence of environmental management infrastructures involves attempts by human agents to extend an existing practice in a particular direction by making interactively stabilised associations between heterogenous elements of a new (extended) practice. These elements are resources produced and transformed in the course of practice (Pickering, 1995). Our particular focus in this study are the artifacts and routines that form key building blocks of infrastructure.

The mangle comprises the intentional structures and social contours of human agency, the culturally enduring procedures of disciplinary agency, and the various forms and performances of material agency (Huvila, 2016). Alignments are not straightforward and require ongoing ‘tuning’ (Pickering, 1995) as resistances emerge at the intersection of these mangled agencies, which in turn trigger contingently formulated accommodations and adjustments to the evolving assemblage of artifacts and routines. Depending on the effectiveness of these responses in circumventing encountered obstacles, the sequence of emergent resistances and attempted accommodations continues in time until a degree of closure is reached through stabilisation (albeit precarious) of the dynamic mangling process (Johnston et al., 2016; Pickering, 1995).

3 Case Background

The EPA is an independent environmental regulator that administers South Australia’s *Environment Protection Act 1993*. In particular, the EPA protects and restores land, air and water quality through the risk-based regulation of pollution and waste. At the time of this study, one of the pressing challenges facing the EPA was addressing the environmental and human health risks and impacts associated with management of the lower reaches of the Murray River (Environment Protection Authority, 2012b). The river is the major source of domestic water supply and also plays a key part in the State’s tourism and recreation economy. However, water quality in the river had significantly declined due to high levels of water extraction, extended drought conditions, and pollution from a range of sources (Department of Water, Land and Biodiversity Conservation, 2009; Environment Protection Authority, 2003b).

One of those sources of pollution is the discharge of untreated greywater from vessels using the river and its associated waterways. The composition and characteristics of greywater depend on the sources and activities from which the water is generated and can vary significantly with respect to both place and time. Potential components include soluble organic compounds derived from chemical products and kitchen waste, suspended solids (including food particles, hair and fibres), dissolved salts such as nitrates and phosphates, other pollutants such as heavy metals, and pathogenic micro-organisms (including bacteria and viruses) (Eriksson et al., 2002). Greywater discharge from vessels can be a significant source of pollution in areas with high levels of recreational boating. In South Australia, the Murray River is home to a thriving houseboat community, many with facilities such as washing machines, dishwashers, ensuite bathrooms and spa baths. With over 2,000 vessels, including some 300 commercial hire boats, it is estimated that up to 500 million litres of untreated greywater could be discharged into the river annually (Environment Protection Authority, 2009b). This practice is problematic with potential effects on aquatic ecosystem health, raw water supply and recreational use of waterways (Environment Protection Authority, 2007a).

In response to the increasing environmental and public health risks associated with the discharge of vessel greywater, the EPA sought to extend its environmental management practice towards a new practice of regulated greywater management. This involved the development of a greywater management infrastructure between 2004 and 2013 to facilitate the monitoring and management of greywater produced by vessels on South Australia’s inland waters. In addition to the planned interventions of the EPA and other human actors, this infrastructure is composed of different forms of materiality that were integral to enacting environmental management in practice (Jensen, 2015), including policies and guidelines, regulatory instruments and standards, technical devices, digital artifacts and databases. The materiality in the greywater management infrastructure could also be extended to encompass natural objects, such as the river itself (Jensen, 2015). Indeed, greywater and its material properties are a key reason why vessel greywater management practice needed to change on South Australia's waterways. However, in this paper we focus primarily on the artifacts and routines that were created to accomplish vessel greywater management.

4 Method

We analyse the development of the greywater management infrastructure from a longitudinal perspective. Consistent with our theoretical perspective, we follow Sandberg & Tsoukas's (2011) suggestions to focus on the sociomaterial performance of practice and what matters to the practitioners. This involved studying what human agents did and why, with different artifacts and in relation to other actors, and with what results, in their attempts to effect change in the form of new or extended environmental management practice.

We collected qualitative empirical data from a ten-year period between 2004 and 2013 using two main sources: participant observation and documentary evidence. Our initial focus was on the Vessel Management System (VMS) developed by the EPA. Data were collected by one of the authors as a 'participant observer' (Walsham, 1995) attached to the EPA between 2010 and 2013. This author was involved in various aspects of the development of the VMS and its ongoing modification as a systems developer and database coordinator. He was therefore able to observe many details of the development of the information system and its operation in practice. His involvement provided access to organisational documentation, screen shots of the evolving system, and various project artifacts. He also participated in interviews held between the developers of the VMS and its stakeholders and users. These interviews covered a range of issues and provided insights into the organisational interests related to the VMS (and the broader environmental management infrastructure), organisational engagement and interaction processes, and drivers and inhibitors of system adoption. Participant observations from the interviews and other development activities were summarised as field note memos.

Data sources	Number of documents
Internal EPA records and correspondence	90
EPA publications	88
Other government department publications	29
Boating industry publications	32
Broadcast, online and print media	63
Total	302

Table 1. Documentary data

To complement the data generated from the participant observation, a wide range of internal and public documents were reviewed, including print and online publications of the EPA (including media releases); internal EPA records such as unpublished reports, meeting minutes, consultation submissions, memos, formal correspondence and emails; publicly available newsletters, reports and white papers from other stakeholder organisations in both government and the boating industry; and media coverage, including newspaper and magazine articles, and television and radio interviews. Table 1 summarises the documentary sources examined in the study. In our findings and analysis, we indicate the source of evidence presented from field note memos or internal EPA documentation in square brackets.

Examples from our data	Significance in our analysis	Theoretical concepts used
Excerpt from an EPA media release: "We're currently developing an agreement with the Department of Transport's Commercial Marine Division that will see the new greywater requirements incorporated into their regular survey and inspection process."	Collaborative relationship to support EPA's vessel audit routine.	Human agency (actors and social relations) Routine (enactment)
Excerpt from the minutes of a VMS project meeting: "System proposed to be in either PHP or J2EE. Check with AIM about standards for typical applications."	Introduction of IT specialists (AIM) with their disciplinary expertise to VMS development	Disciplinary agency (knowledge and conceptual schemes) Technical artifact (form)
Excerpt from an industry magazine: "EPA Officers joined representatives from the Boating Industry Association of SA (BIASA) … on a 10 day survey of the River Murray … The EPA also quantified the location and numbers of inland vessels, and recorded the registration details of all vessels that were not previously on the EPA's vessel management database."	Engagement with boating industry stakeholder. Example of vessel audit in action and use of VMS in that practice.	Human agency (actors and social relations) Routine (enactment) Technical artifact (function)
Excerpt from a VMS project email and screenshot: "Can we under this page make a pull down box that we can choose to retrieve inland vessels only. Apparently as soon as you put a compliance date in for privates whether marine or inland they all come up within the search function. So we sent a few inland letters to marine vessel owners."	Modification to the VMS as a result of a problem encountered in practice. Depiction of VMS web-based interface over Oracle RDBMS.	Technical artifact (form and function) Material agency (producing resistance) Accommodation (revision to artifact)
Excerpt from a regional news item: "He says the EPA had given people a longer grace period because of the low river levels. 'We've got to the point where we no longer think that's the right approach and we're going to start being more forceful in our enforcement of the regulations,' he said."	Delay to enforcement of greywater requirements due to low river levels. Intention to change approach to enforcing regulatory compliance.	Material agency (river conditions producing resistance) Human agency (goals and planned interventions) Accommodation (revision to goals)
Excerpt from an EPA internal report: "SUMMARY OF COMMENT: Small vessels should be exempted from having to make structural alterations to contain wastewaters … RESPONSE: The code provides for a number of management strategies to prevent the discharge of vessel wastewaters and has introduced compliance dates to reflect the size and use made of vessel … OUTCOMES: <u>MODIFICATION</u>"	Example of submission from public consultation and EPA's response. Refers to provisions of the greywater CoP. Modification of the CoP to a phased implementation of greywater compliance requirements.	Human agency (actors and social relations) Material agency (vessel size producing resistance) Social artifact (function) Accommodation (revision to artifact)

Table 2. Interpretive template

As we explored the VMS and its development it became clear that we needed to extend our case study back in time in order to understand the conditions from which the VMS emerged. Consequently, we expanded our data collection to include documentary evidence from 2004. This introduced new artifacts, such as a Code of Practice (CoP) covering vessel greywater management, and new social actors, such as the South Australian Department of Transport. The start and end points of our analysis are somewhat arbitrary as the 'biography' of an information system extends in either direction, with nominal beginnings reflecting the accumulation of earlier decisions and actions, and future adjustments and adaptations equally likely (Leonardi, 2011; Williams & Pollock, 2012).

The first stage of our data analysis involved assembling the various documents and field note memos comprising our data in chronological order. This enabled us to construct a timeline of events and activities and associate together accounts of these from different actors. Based on an interpretive research approach, our initial reading of the empirical material focused on content, context and process of change (Walsham, 1995). Our coding of the data identified the main actors involved, their stated interests and concerns, the arguments that they articulated in relation to the issue of vessel greywater management, the various actions they undertook, and the tools and artifacts they utilised in those activities. Based on this initial coding, we developed a case narrative that outlined the basic process involved in the emergence of the VMS and the greywater management infrastructure in which it is embedded. This focus on the temporal unfolding of the case study is appropriate given our subsequent emphasis on mangling and emergence (Venters et al., 2014).

In the second stage of analysis, we used the main elements of our theoretical perspective as a lens with which to interrogate our empirical data (Venters et al., 2014). Initially, we read our case narrative to identify instances of resistance and accommodation. For each of these, we examined the relevant data for indicators of when and where different agencies were exercised. We then explored the contours of each agency, focusing on who or what was acting and why, the performative effects that resulted, and the relationship with other agencies. In doing so, we were guided by Pickering's (1995) admonition to concentrate on exactly what gets mangled. While our analysis in this stage was shaped by the main elements of the mangle, we treated these "as sensitising theoretical concepts … rather than mechanistically applied categories" (Symon & Pritchard, 2014, p. 248). Examples of how we interpreted our data in this stage of the analysis are presented in Table 2.

In the final stage of analysis, we used our conceptualisation of the extension of material practice as discussed in Section 2 to guide our analysis in terms of temporal emergence through sequences of resistance and accommodation. We analytically defined two main episodes of mangling that we considered important in developing a process explanation of infrastructural emergence. These structure the presentation of our findings and analysis.

5 Findings and Analysis

Our analysis of the empirical evidence demonstrates how the artifacts and routines comprising the emergent greywater management infrastructure were the products of the mangling of human, disciplinary and material agencies in the practices of its developers and users. Figure 1 below summarises the sequence of events and activities and the two key (sometimes overlapping) mangling episodes that we delineated in the development of the EPA's new greywater management practice. The following sections can be read alongside Figure 1.

5.1 Episode 1: Mangling to regulate

By early 2003, the need to address the degraded state of the South Australia's waterways had gained considerable official and public acceptance (Environment Protection Authority, 2003b). Attention increasingly focused on the handling of greywater produced on vessels using the waterways, which was being discharged directly into the aquatic environment. Previously, few vessel owners and boating industry operators had been concerned about its environmental impact (Gallagher & Wigley, 2001; Salter, 2001). However, the publication of a local government report on the ecological impact of houseboats on the Murray River highlighted the significance of greywater pollution and lobbied the EPA to investigate its impact (Gallagher & Wigley, 2001).

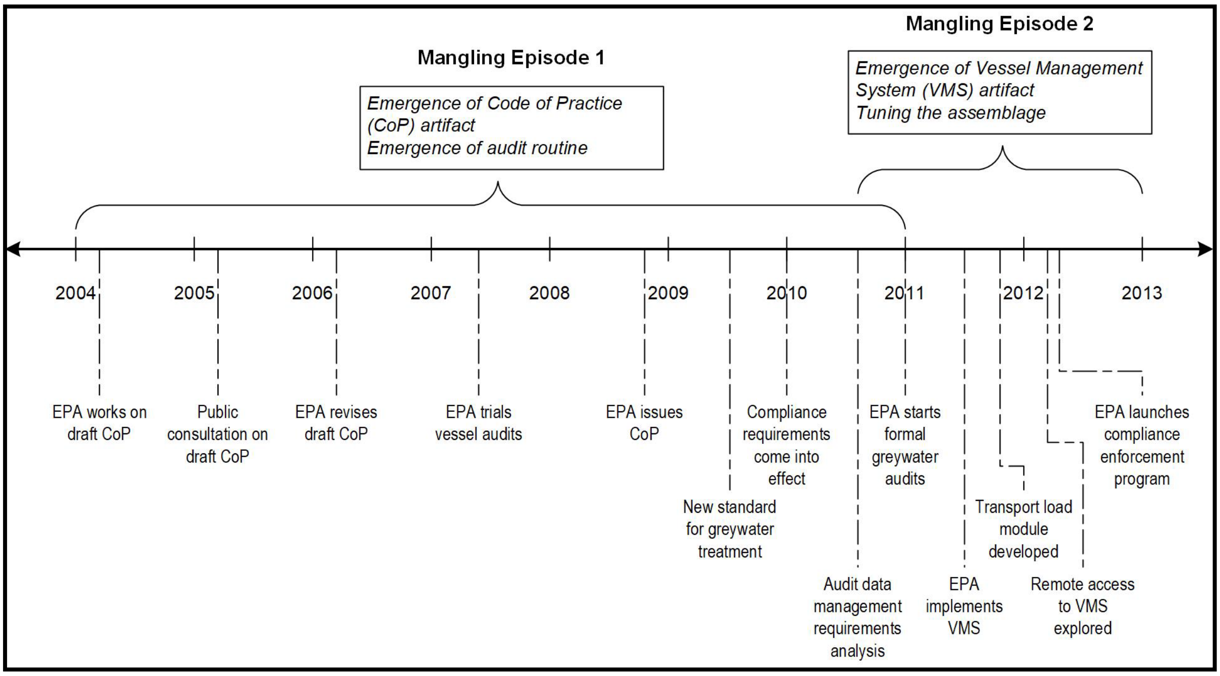

Figure 1. Greywater management timeline

In response to the heightened importance of water quality issues, the EPA considered the development of a strategy to manage greywater discharge from vessels using the river (Environment Protection Authority, 2002). Perhaps unsurprisingly, the EPA decided on the goal of regulating greywater discharge. Its institutional position and status as an environmental regulator conditioned the intentional structure of its agency so that pursuing a regulatory approach to the issue of greywater management was the obvious choice. Thus, the goal of the EPA became to extend its existing environmental management practice to encompass vessel greywater management. Extending its practice along this particular direction involved establishing a position that defined environmental regulation as a desired and legitimate future state for vessel greywater management.

The vehicle for achieving this desired end state lay in a recently approved Environment Protection (Water Quality) Policy 2003. An environment protection policy is a legislative tool under the State of South Australia's *Environment Protection Act 1993*. The release of the water quality environment protection policy provided for a consistent approach to addressing degradation in water quality across South Australian water bodies (Environment Protection Authority, 2001). It set water quality objectives, established general obligations to manage and control pollution, and encouraged better use of wastewater. The environment protection policy also specified additional obligations relating to wastewater discharge, including the operation of vessels on the State's rivers and lakes (Environment Protection Authority, 2003a). In particular, the environment protection policy incorporated an earlier requirement that blackwater produced on vessels be contained for subsequent on-land disposal, but went further in also providing a requirement, at an unspecified future date, for the containment or treatment of greywater. Central to the EPA's strategy for managing vessel greywater discharge was the realisation of the obligations and provisions outlined in the newly approved water quality environment protection policy. While the environment protection policy acknowledged the need for vessel greywater management, the details of how this would be achieved would need to be developed by the EPA. Without establishing measurable outcomes, appropriate practices that users of vessels could follow, and viable monitoring and enforcement mechanisms, the EPA would be constrained in its ability to ensure user compliance with the provisions of the environment protection policy and prevent pollution from this source.

Emergence of the Code of Practice artifact

In working towards its goal of regulating vessel greywater, the EPA copied elements of its existing environmental management practice into the new practice. That is, once the EPA decided on the path of regulation, the regulatory framework under which it operated provided a set of generalisable procedures (Chae & Poole, 2005) that the EPA could apply in furthering its goal – an exercise of disciplinary agency. In particular, this involved the creation of a regulatory artifact called a 'code of practice'. A CoP examines the impact of a particular activity and articulates practical and measurable outcomes for its regulation. It is a set of rules that details specific behaviours for complying with a particular environment protection policy. A CoP describes both requirements, which 'must' be observed to avoid breaching the provisions of the environment protection policy to which it is linked, and recommended practices, which 'should' be followed to achieve the desired outcomes. Under the provisions of the *Environment Protection Act 1993*, compliance with a CoP's requirements can be enforced through the issuing of an environment protection order (Environment Protection Authority, 2019), but its agency is primarily exercised through collective acceptance of the guidelines and rules for acceptable behaviour that it articulates.

Regulation of vessel greywater management would have a greater chance of being effective and accepted in practice if the CoP for vessel greywater management was constructed collaboratively with those most affected. Thus, the process the EPA followed in developing the greywater CoP involved extensive consultation and negotiation with stakeholders in the boating industry, local government and the community (an exercise of the EPA's human agency). This process needed to facilitate convergence on a set of rules for vessel greywater practice that could shape behaviours upholding environment sustainability. At the same time, it needed to offer opportunities for the industry and the wider public to identify issues with the emerging rules and for these to be resolved before the CoP came into effect.

To this end, the EPA established an external advisory group, which consisted of twenty-five representatives from local business and vessel facilities, commercial and recreational vessel operators, state and local government, and boating industry associations. Composition of the external advisory group deliberately included key stakeholders of South Australia's waterways, both those directly or indirectly engaged in maritime activity and those affected by the threat to water quality. The external advisory group met on repeated occasions during 2004 to discuss and draft an initial CoP that would implement best practice in environmental management for the sustainable use of South Australia's aquatic environments, including "reasonable and practicable measures" to prevent the discharge of untreated greywater from vessels on inland waters (Environment Protection Authority, 2008a, p. 59).

In order to be reasonable and practicable, the draft rules needed to be based on an understanding of the boating industry's operational practices, the specific risks of greywater for water quality, the effects on environmental and human health, and potential greywater containment or treatment solutions. To inform the drafting process, the EPA and the external advisory group conducted a series of site visits in early 2004 to collect information on the industry's current environmental performance. The EPA also commissioned a report that investigated the impact of untreated greywater on water quality, reviewed the regulation of greywater discharge in a range of other countries, recommended minimum water quality standards for treated greywater, and reported on the availability of potential on-board greywater treatment systems (Environment Protection Authority, 2004, as cited in Northwest Hydraulic Consultants, 2010). Further, the EPA was able to draw on the results of a large risk assessment project initiated in 2004 to identify specific hazards to water quality along the Murray River and recommend appropriate risk management options (Environment Protection Authority, 2007a).

The knowledge produced in these reports was useful in providing the EPA with a credible, scientific basis for the need to change existing behaviours around the handling of vessel greywater. In a sense, the EPA was seeking to enrol the agency of scientific knowledge. Comprised of facts, conceptual representations, relationships and classifications, such systematic and formalised knowledge has a performative power, not just reflecting the world but intervening in it and contributing to its constitution (Callon, 2007; Jones, 2014). For example, specific numerical criteria for a range of parameters eventually became incorporated into the CoP as indicators of acceptable water quality after the onboard treatment of vessel greywater (Table 3). These scientific statements defined when greywater was polluting and when it was not, effectively constituting treated greywater (meeting these criteria) as no longer wastewater.

	Inland waters vessel operators must (required outcomes):
1	not permit grey water to enter into any inland waters by: – retaining grey water on board the vessel for disposal into land-based wastewater collection system – ensuring that the vessel's fixed grey water holding tank meet the requirements outlined in …
2	only discharge treated grey water if the following criteria are met (dilution is not acceptable): – suspended solids less than 50 mg/L, – a total grease content of less than 25 mg/L, – nitrogen content less than 10 mg/L, – phosphorous content less than 1 mg/L, – Enterococci of less than 40 cells per 100 mL, and – biochemical oxygen demand is reduced by digestion, oxidation or other recognised treatment method.
…	

Table 3. Examples of greywater management rules (from Environment Protection Authority, 2008a, p. 60)

The draft CoP underwent several iterations during 2004 with revisions to various details made after discussion and resolution of points raised by the external advisory group members, including aspects related to the feasibility of greywater storage, treatment and discharge quality. This represented the initial tuning (Pickering, 1995) of the incipient CoP artifact as points proposed by the EPA were accepted or contested by external advisory group members to a varying degree (an exercise of their agency), triggering a series of modifications to the draft in order to secure consensus. When a final draft of the rules had been agreed with the external advisory group, the EPA released the draft CoP for state-wide consultation and public comment in early 2005. The aim of the consultation process was to engage stakeholders to review the draft CoP, both as a means of increasing its validity and as a source of constructive feedback for further revision. Over 50 submissions were received from a range of stakeholders, including many industry operators. These were carefully considered by the EPA and relevant comments were either responded to with a justification for why the proposed changes could not be accommodated or addressed through modification of the draft CoP in a process of further tuning. For example, in response to concerns about the structural limitations and cost of modifying small vessels to deal with greywater, a range of management strategies including behaviour change were included in the CoP "in order to recognise the social and economic status of all vessel operators" [EPA internal report, August 2007]. Similarly, the CoP introduced a series of compliance dates intended to reflect the size and use made of different vessels. In another example, expressed concerns about permanently moored vessels on the Murray River resulted in the CoP requiring "a higher level of environment protection and compliance for these types of vessels and their operators" [EPA internal report, August 2007].

The rules that emerged from the work of the EPA and the external advisory group and the ensuing consultation process were eventually issued as *the Code of Practice for Vessel and Facility Management (Marine and Inland Waters)* in 2008 (Environment Protection Authority, 2008a). The greywater management requirements applied to all commercial and private vessels operating on inland waters but would be phased in over three years depending on the type of vessel (Environment Protection Authority, 2008b). From the EPA viewpoint, the rules prescribed specific behaviours and the conditions under which they were acceptable (or not) and aligned these with the broader environmental protection goals. With respect to the management of vessel greywater, the resultant CoP defined two possible required outcomes (Table 3): either preventing greywater from entering waterways or only discharging treated greywater. Vessel owners and operators had the option to retain greywater onboard in holding tanks for subsequent disposal at some 13 specific land-based pump out stations along the 650km South Australian part of the Murray River (Department of Water, Land and Biodiversity Conservation, 2009). However, the stations were often difficult to access due to the distance between stations, the number of vessels attempting to use them, or drought conditions affecting river levels – arguably, an exercise of the material agency of the river itself. As a result, the CoP also included provisions that allowed vessels to discharge greywater into the river after it had been adequately treated onboard (e.g., by suitable filtering). The CoP outlined a further 17 recommended practices that assisted vessel owners and operators to minimise the environmental impact of greywater (Environment Protection Authority, 2008a).

The CoP was the product of the mangling of various human and disciplinary agencies. As a social artifact it was a material piece of the culture surrounding environmental governance and regulation in South Australia. Circulated, the CoP was capable of serving a specific end in the practical accomplishment of water quality objectives (M. C. Suchman, 2003; Verbeek & Vermaas, 2009). The rules and recommended practices to govern vessel greywater management encapsulated in the CoP were specific and actionable. Adherence to them by vessel owners and operators would bring about the desired change to the existing greywater management behaviour and reduce the risk of greywater pollution. However, to be effective the rules had to be applied and observed consistently across South Australia. Their formulation as a CoP within the State's legal and regulatory framework produced a device that the EPA could use to enforce compliance with these provisions.

Emergence of the audit routine

Although the intention of the CoP was "to encourage best environmental management practices for the benefit of future generations" (Environment Protection Authority, 2008a, p. 1), enforcement of the CoP regulations was eventually perceived as a necessary and effective course of action for the EPA: "Gaining compliance through regulation was really the only option for managing greywater discharges" [Field note memo #8]. Enforcing regulatory compliance implied the need to monitor the manner and extent to which vessel owners and operators were complying with the CoP. Data had to be collected via systematic monitoring to evidence when greywater management practice was compliant with the CoP and when it was not. The evidence collected could then be used by the EPA to monitor compliance progress and, if necessary, enforce the CoP by issuing environment protection orders to continued non-compliers. Monitoring compliance with greywater requirements was achieved through a vessel 'audit' routine (Environment Protection Authority, 2012a, 2015), first trialled in 2007 to ensure houseboats along the Murray River had appropriate blackwater disposal systems (Environment Protection Authority, 2007b). The experience gained in conducting the blackwater audits was influential in shaping the EPA's performance of the greywater audits, which commenced from 2011 (Department of Planning, Transport and Infrastructure, 2010).

The audit routine involved EPA officers collecting compliance data during inspections of vessels in the field. Collected data included information about the owners or operators, the manner in which greywater was managed, and whether it was compliant with the CoP. Vessels were typically deemed to be compliant with the CoP in relation to greywater management, when an EPA officer could establish, in audits, that vessels had installed and were using an approved greywater treatment system that filtered greywater to the specifications prescribed in the CoP. 'Approved' greywater treatment systems were those that met a new standard (AS 4995) specifically developed by Standards Australia to provide an industry benchmark and accreditation system for the design, construction, installation and operation of onboard greywater treatment systems for vessels operated on inland waters (Environment Protection Authority, 2008b, 2009a; Standards Australia, 2009). The large number of vessels operating on South Australia's inland waters, the majority of them privately owned vessels, necessitated the use of random audits (Environment Protection Authority, 2012a). Some audits targeted specific geographical areas, generally those with wharves, marinas and thus concentrations of vessels. Alternatively, EPA officers would hire a houseboat and sail it along different reaches of the Murray River, auditing every vessel seen along the way. Smaller audits would typically cover 30-50 vessels, while larger audits could cover up to 100 vessels.

EPA staff needed some means of handling the data produced from the vessel audits. Thus, intertwined with the new audit routine, a spreadsheet-based information system emerged. Compliance data were collected manually in the field on paper forms and subsequently entered into spreadsheets at the EPA office. Image-based evidence documenting compliance complemented the vessel records in the spreadsheets. For example, a large number of photos were taken of each audited vessel. The photos and scanned copies of the original audit forms were archived in electronic folders in the EPA network that, in time, grew in size and complexity, making quick retrieval difficult and impractical: "The photos would simply be lumped together in a folder archived somewhere within the EPA network, and rarely looked at" [Field note memo #1].

Commercially operated vessels were handled differently, in collaboration with another South Australian regulator. Since all commercial vessels operating in South Australia were surveyed biennially by the Department of Transport, it made sense for that department to incorporate a check for greywater management compliance in their inspection and certification process

(Environment Protection Authority, 2009b). They shared this and other relevant data on the commercial vessels, including vessel identification and ownership information, with the EPA. The data were received periodically in the form of a large spreadsheet. The information it provided was important for maintaining up-to-date records of addresses for correspondence and for maintaining accurate records of vessels that go in and out of survey.

However, the EPA staff encountered challenges in their handling of the vessel audit data. The process of paper-based data capture in the field followed by transfer of that data to spreadsheets was inefficient and prone to errors. In addition, the new audit routine generated large volumes of data that were difficult to manage and lacked consistency. Subsequent processing of the data was therefore complex and challenging. Typically, this entailed aggregation and disaggregation of data at different levels of granularity to fulfil the needs of different stakeholders. For example, stakeholders within the EPA and outside it, such as other government departments and industry associations, needed different types of reports. Additionally, the EPA tracked all correspondence to vessel owners and operators that formalised the findings of EPA officers during audits, and which required further action if the requirements of the CoP were breached.

5.2 Episode 2: Mangling to informate

Emergence of the Vessel Management System artifact

EPA staff perceived that their use of spreadsheets to store and manipulate audit data would constrain their ability to monitor vessel greywater management compliance efficiently and effectively: "Team members had identified that the current way the data was stored, using spreadsheets, was inefficient and time consuming" [Field note memo #7]. The limitations in the EPA's performance of data management constituted a material resistance, a technological barrier to the EPA's goal of creating a new regulated vessel greywater management practice. Consequently, they looked for a means to overcome these limitations, by "designing the system to speed things up" [Field note memo #7]. In the second half of 2010, a small team at the EPA commenced work on a requirements analysis and possible system functions for a new 'vessel management system'.

The decision to develop the VMS in-house introduced a new set of human agents in the form of the EPA's Applications and Information Management group. As information technology specialists, they would be likely to draw on existing material and disciplinary elements that were familiar and relevant to them, including programming languages and development platforms (Chae & Poole, 2005). A decision was taken to develop the VMS using Oracle Database, a well-established relational database management system. As the VMS developers sought to harness the material agency of this platform, the data that were previously stored in spreadsheets were restructured based on the pre-programmed requirements of the system, which redefined granularity in the way the data were specified and stored in a relational database. The VMS user interface was developed using a web-based development tool. Development proceeded quickly, with user testing and an early demonstration of the VMS announced in early 2011.

A key aspect of the new system was greater integration and consistency of the extensive data collected and maintained about individual vessels. These included ownership details, descriptions of on-board facilities (different types of facility were capable of producing greywater to varying extents) and multiple greywater treatment options (depending on the type of facility), as well as details of any onboard greywater treatment system installed (e.g., technical specifications, manufacturer information, model and serial number, installation and maintenance dates), and the presence and status of any issues or defects that might affect a vessel's compliance. As noted above, the vessel audits produced a large amount of associated image-based evidence, such as photographs, that could change over time. Consequently, a photo album feature was implemented in the VMS that enabled the building of image galleries for each vessel, with the capacity to store any number of photos necessary along with specific audit comments by EPA officers for each photo, including dates and other contextual information about objects featured in the photo.

Correspondence record management was another important aspect of the EPA's monitoring activity that influenced the development of the new VMS. Previously, EPA officers had undertaken mass mail-outs to vessel owners and operators asking for their plans on how they intended to become compliant with the CoP. These letters generated a substantial subsequent correspondence that needed to be stored and differentiated in the database: "We are getting a large amount of correspondence from vessel owners claiming that their vessel is now compliant with all greywater requirements" [VMS project email, April 2011]. The VMS needed to distinguish these owners as 'pending' compliance, until their vessel was inspected. Only then would a compliance letter be issued. Similarly, they needed to be excluded from any future correspondence sent to 'non-compliant' vessel owners. It was also desirable that the new system had the functionality to automatically generate certain standard letters at different points in the compliance process, such as the compliance reminder letters.

A major issue facing the VMS developers was how to capture and integrate the data relating to commercial vessels received from the Department of Transport: "[We] had to think creatively to come up with solutions to other problems. Such things included … storing the data that is obtained from Transport" [Field note memo #7]. To facilitate more frequent sharing of data, a 'load module' was built for the VMS that could be used to update the VMS database based on changes in Department of Transport's records. The database structures used by the two regulators were significantly different, with the VMS holding more information on a vessel, so development of the load module required a large amount of coding and discussions between the two agencies. The role of the load module was to regularly input the Department of Transport data into a contained section of the VMS database and identify any differences between the records, which EPA officers could then choose to update (or not) in the main VMS schema. A change history allowed users to view or undo changes to maintain the data integrity of the EPA records. In a very real way, the material performativity of the VMS was mangled with the need for the EPA to work with the Department of Transport. The nature of the collaborative relationship and the material form of the VMS emerged together in practice and interactively stabilised each other (Pickering, 1995).

As the EPA staff involved in compliance monitoring became familiar with the new VMS, they proposed improvements to the way data were processed or recognised other opportunities to exploit the potential of a database-driven solution. Consequently, the system developers continually adjusted the functionality of the VMS in a process of incremental improvement. For example, early in the development process one EPA officer asked: "Can we please add another field to the database, which names the manager of the commercial houseboats? Many houseboat companies manage a fleet of vessels (but they don't own them) and [that] would be good to distinguish" [VMS project email, October 2010]. In another example, while the various boating industry associations in South Australia did not actually own vessels, they were closely involved in the development of the CoP and the subsequent compliance monitoring regime. It was decided to include them in the VMS as a special class of 'owner', thereby leveraging the system's functionality to record EPA advice and handle the considerable correspondence the EPA had with these associations: "These have been created due to the need to store the correspondence that the EPA has with these organisations in a centralised location" [Field note memo #2]. Similarly, the realisation that over time vessels would be on-sold meant that changes in ownership needed to be tracked so that all correspondence associated with a specific vessel could be maintained: "An owner history was developed for VMS, where all previous owners and all correspondence with previous owners would be recorded" [Field note memo #6]. In ways such as these, the material form and functionality of the VMS was shaped by its entanglement with the vessel audit routine and the human agency of its users as they explored its possibilities.

Tuning the assemblage

During 2011, EPA officers began using the VMS in their regular work, so that the VMS quickly became central to the EPA's enactment of the vessel audit routine and performing key functions in their monitoring and compliance activities. For example, EPA officers conducted a 10-day survey of a large section of the Murray River, noting the location and numbers of vessels, and recording the registration details of all vessels that were not previously in the VMS. Their owners were then sent letters describing the greywater management requirements for vessels on inland waters and their obligation to comply with these requirements (Spencer, 2011).

The performativity of the VMS greatly facilitated ease of access to relevant vessel information, efficient records management, flexible and structured report generation, communication with vessel owners, and information exchange with other regulators and agencies. Its functionality allowed the EPA to maintain up-to-date information concerning a vessel's history and current compliance status. Using the VMS, EPA officers could easily identify non-compliant vessel owners, send out warnings, and locate correspondence history concerning underlying causes and any ensuing course of action taken. Because data were centralised, authorised EPA officers could access historical information about individual vessels including specific advice and recommendations provided at prior inspections, thus avoiding duplicate or contradictory actions. It was also useful because it constituted a complete record for each vessel that could potentially be used as evidence when environment protection orders were issued, and legal action taken against vessel operators failing to comply with the requirements of the CoP.

The improved data processing and management offered by the VMS encouraged EPA staff involved in monitoring vessel greywater compliance to envisage ways that the system could be used to enhance their audit routine. For example, an EPA officer asked a VMS developer to extend an initial reporting function to a finer-grained level of analysis: "Could you incorporate into each of the different audits on VMS a similar compliance summary report as you have used in the overall compliance summary?" [VMS project email, September 2011]. Another example involved task management and the multitude of compliance dates that EPA officers were responsible for keeping track of. While the initial VMS allowed users to search and find all vessels that were nearing or past their compliance due date, "action items were developed to allow the system to have a task managing capacity" [Field note memo #2]. The new functionality allowed EPA officers to set dates for particular actions that needed to be completed or followed up on, triggering subsequent system-generated reminders on login when the relevant date arrived. These examples demonstrate how the progressive tuning of the audit routine and the accompanying changes in how the EPA audit staff worked could not have occurred in the ways they did apart from the material form of the VMS.

By early 2012, the requirement introduced by the CoP for onboard containment or treatment of greywater on all commercial and private vessels operating on inland waters was fully phased in. While some 60% of commercial vessels had become compliant, in order to achieve equity across the boating industry the EPA launched the next phase of the vessel greywater compliance program, involving further inspections, warning letters and, if necessary, environment protection orders (Environment Protection Authority, 2012a): "Regulation [enforcement] was only implemented following a significant education and consultation campaign. The houseboat industry as well as representatives from the private/recreational vessel owners were engaged and helped to develop the mechanism for transitioning the South Australian houseboat fleet to best practice and vessel greywater management. Regulation [enforcement] was only the final phase in the program to ensure equity across the fleet" [Field note memo #8].

As one EPA representative commented, "We've got to the point where … we're going to start being more forceful in our enforcement of the regulations" (Australian Broadcasting Corporation, 2012). Arguably, the mangling of the material agency of the VMS, in facilitating and streamlining the monitoring of greywater management, with the human agency of the EPA officers, who intended to "ramp up" (Australian Broadcasting Corporation, 2012) their efforts, enabled the enhancement of the vessel audit routine towards ensuring more complete regulatory compliance.

In increasing their activities around ensuring vessel greywater compliance, EPA staff encountered further resistances affecting the efficacy of their practical monitoring work. These constraints prompted the EPA to consider and develop refinements in both the VMS and the manner in which it was used in practice in attempted accommodations to overcome them. One issue revolved around data verification in the field. The VMS was located inside the EPA's intranet and could not be accessed externally, for example by EPA officers conducting a vessel audit. This meant that when talking with vessel operators and owners about greywater management and their vessel's compliance status, officers did not have real-time access to up-to-date information held in the VMS. During an audit, some vessels owners would make claims to EPA officers in relation to specific compliance issues. Without access to the VMS, officers were unable to verify these claims or provide appropriate advice.

The material configuration of the VMS was constraining the ability of EPA officers to operate efficiently and effectively in the field. The EPA and its VMS developers were receptive to enhancing the mobility of the VMS and work began on a solution. New functionality was developed that enabled a version of the VMS database to be copied before an audit onto a handheld computer specifically designed to withstand rough handling in field conditions. Taken with the EPA officers on a vessel audit, this arrangement provided the officers with the ability to access up-to-date records while working at a distance from their office. The human agency of the EPA officers was thus mangled with the material performativity of the mobile device to extend the reach of the VMS.

Another issue identified by EPA officers concerned the behaviour of some vessel operators that in effect circumvented the greywater treatment requirements of the CoP. It became apparent that on occasion vessel operators were disconnecting their vessel's greywater treatment system and using the overflow pipe attached to the system to discharge untreated greywater directly into the river. Typically, this action was resorted to when the installed greywater treatment system did not operate as intended or stopped working during a voyage – a failure in the material agency of the treatment system upon which the vessel operator was relying to be compliant with the CoP. The reliability of the treatment systems approved for use under the CoP was becoming of increasing concern for houseboat owners. Nevertheless, the EPA was insistent that compliance was necessary, even if that meant containing the greywater onboard until it could be pumped out at one of the disposal stations along the river (Jean, 2012).

The non-compliant use of overflow pipes prompted consideration by the EPA on how best to fix the problem. At the time data collection ended in 2013, the envisaged solution involved attaching an 'overflow tag' to the overflow pipes or taps in a vessel's greywater treatment system. The tag would break if the pipe was used to discharge greywater, and the date would be automatically recorded. Overflow tag data would be captured during vessel audits and surveys and included in the VMS database as part of the compliance history for vessels when applicable. A new VMS function would be developed to track the overflow tag data. The material agency of the overflow tags and the VMS would together afford the possibility of a more accurate and effective performance of the vessel greywater audit routine.

Over time, the greywater management infrastructure introduced by the EPA was successful in achieving a high level of compliance for vessels operating South Australia's inland waters (Brennan, 2013). Data retrieved from the VMS in early 2014 indicated that 82% of commercial vessels and 77% of recreational vessels on inland waters were greywater compliant with the CoP, with the most common reasons for non-compliance being significant financial constraints, absentee or new owners and extreme climate events. As the heterogeneous arrangements based around the vessel audit routine and the CoP and VMS artifacts stabilised, the EPA began to turn its attention to vessels operating in the State's offshore waters. This would involve a further extension of greywater management practice to a new environment: "Once we start to get on top of the vessels on inland waters we will need to turn our focus to marine waters" [VMS project email, April 2011].

5.3 Emergence of environmental management infrastructure

Our analysis has explored how the genesis, form and function of an environmental information system lay in its inclusion within a broader infrastructure developed to support a particular environmental management practice. This infrastructure was a heterogeneous assemblage of individual and collective human agents, regulatory and technological artifacts, and the sociomaterial routines in which they were incorporated. Figure 2 depicts our conceptualisation of the emergence of this environmental management infrastructure.

Consistent with the mangling approach we have taken to practice and its change (Pickering, 1995), we view infrastructure as the interactive stabilisation of entangled artifacts and routines (visualised as entwined strands of a rope). An orthogonal cut (Baygi et al., 2021) through the whole assemblage reveals the dynamic mangle of human, disciplinary and material agencies. This mangling includes transformations in the material form and function of various social and technical artifacts, and the production of disciplined human performances in which human intentionality, conceptual understandings, and relations between social actors are transformed. Critically, infrastructure evolves from the field of existing artifacts, practices and disciplines, which collectively constitute the 'surface of emergence' for its open-ended development. This in turn requires ongoing 'tuning' in order to stabilise the heterogeneous arrangements in the evolving assemblage of artifacts and routines.

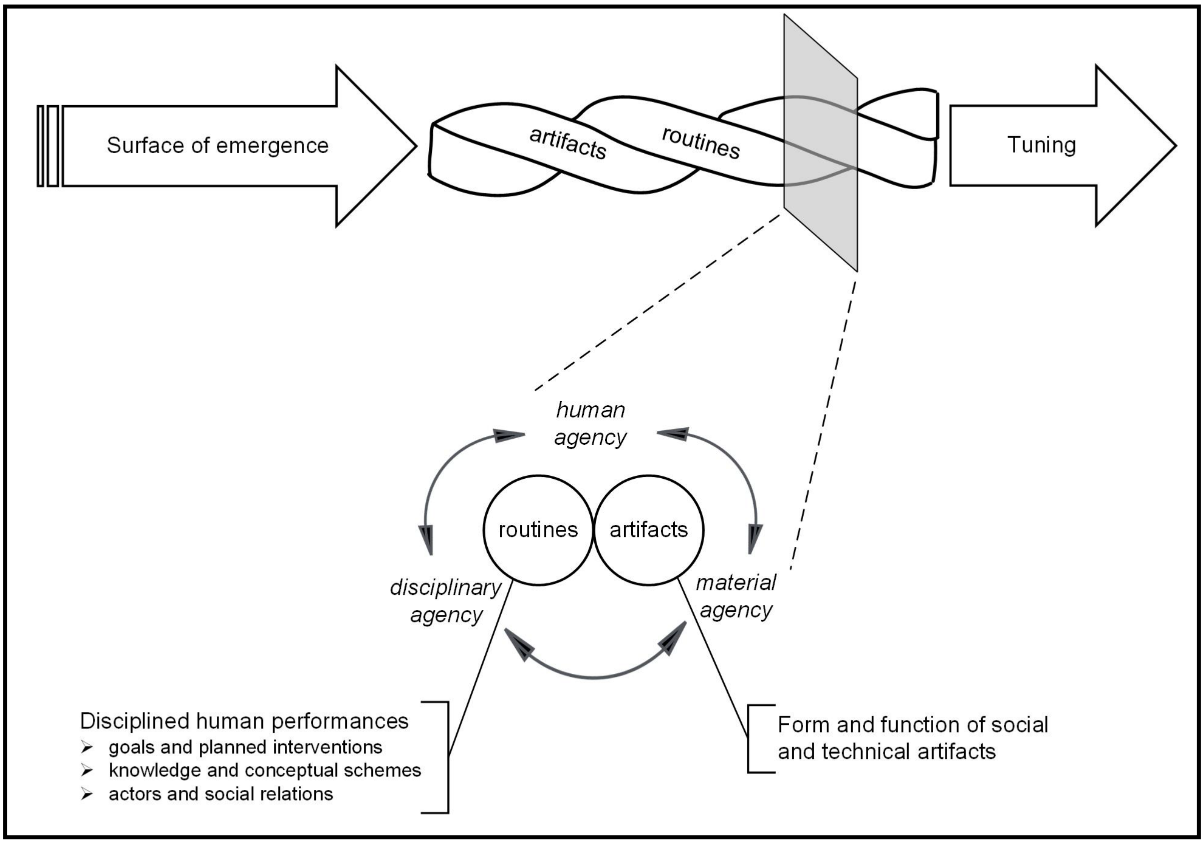

Figure 2. Emergence of environmental management infrastructure

6 Discussion

Based on our analysis of the emergence of an environmental management infrastructure, we suggest four central implications for understanding how information systems become an integral part of environmental management practice.

6.1 Looking back and looking forward

Our findings suggest that an environmental information system is neither a stand-alone artifact nor acontextual. It is located within and emerges from a broader infrastructure of environmental management. As such, it has a biography that includes a past and a future. This quality of temporal emergence (Pickering, 1995) highlights how its current state arises from its previous history and context, and how it is in a process of continual becoming (Abbott, 2016; Pickering, 2008). In our analysis, we highlighted the material transformations that the VMS underwent in its evolution from a spreadsheet-based precursor to a computer-based information system disciplined by the properties of relational database management, and its ongoing modification in response to requirements arising from its use in practice.

The development of the VMS was intimately intertwined with the EPA's attempt to extend its environmental management practice around the issue of vessel greywater management. Following Pickering's (1995) extension of practice, this involved the EPA envisioning a desired future state, selecting an approach that would get them there from their existing practice, and working in real time to find out where that approach led. The form and outcome of this process could not be known in advance. Thus, temporal emergence is also characteristic of the environmental management infrastructures in which information systems are embedded. Our analysis demonstrates how the trajectory of emergence (Pickering, 1995) of the greywater management infrastructure developed by the EPA reflects the consequences of choices made and actions taken at particular junctures: "a chain of multidimensional links which continue to expand from previous assemblages and new actions" (Abbott, 2016, p. 241). This trajectory is not a predictable path. Environmental management infrastructures unfold in a non-deterministic way in the real time of practice. This means that one cannot know ex ante the shape of the infrastructure (and its parts), nor its future evolution (Ciborra & Hanseth, 2000).

Emergence of both environmental information systems and infrastructures is a consequence of the mangle. The EPA's extension of their environmental management practice to encompass vessel greywater management included the creation of artifacts such as the CoP and VMS and their incorporation in the vessel audit routine. The intersection of different agencies in the arrangements that the EPA instigated produced a sequence of different challenges to their successful performance. In turn, human agents monitoring those performances put in place various accommodations that contingently responded to or attempted to circumvent resistances that arose as the infrastructure pushed back. At each stage of the trajectory of emergence, the mangle was in operation. The new practice of vessel greywater management needed ongoing tuning to adjust the contours of the different agencies involved and enrol them in pursuit of the EPA's goals. This tuning constituted a learning process, the results of which the EPA successfully translated into a high level of regulatory compliance for vessels on South Australia's inland waters (and ultimately was able to contemplate extending even further to the marine environment).

6.2 Shifting focus

The EPA's engagement with the world in extending its practice was not simply a straightforward capture of the material agency of information technology. It also involved the production and deployment of knowledge in particular forms (e.g. knowledge of the properties of greywater, the delineation of known hazards and risks to water quality), the exploration and establishment of social relations with other actors, and the fabrication of social artifacts such as regulatory devices. This meant that the EPA needed to assemble, align and make associations between a diverse assemblage of human and nonhuman elements – an interactive stabilisation of human and material performances (Pickering, 1995).

In this emergent assemblage, a range of nonhuman agencies were relevant and imposed themselves on the work of the EPA. Notwithstanding the fundamental role of naturally occurring objects (e.g. the characteristics of greywater that constitute it as pollution, the effect of low river levels on access to land-based wastewater disposal stations), the material forms and performances of a range of social and technical artifacts were influential in this regard. While the VMS improved the efficiency and effectiveness of audit data processing through the performance of its programming, the CoP prescribed regulatory compliance through its collective endorsement by the different stakeholders implicated in its circulation (e.g., the EPA, the boating community, other users of the Murray River). It was the practical instantiation of abstract concepts (Leonardi, 2010) – 'musts' and 'shoulds' (Environment Protection Authority, 2019) made material and given force through the status and position of the CoP in the South Australian environmental legal and regulatory framework.

Acknowledging nonhuman performativity means affording an active role to natural and made objects in the development and operation of environmental management infrastructures. It necessitates a shift in focus to make visible the entanglement of human actors and nonhuman entities that traced out the trajectory of the EPA's environmental management practice (Pickering, 1995). This is a posthumanist decentring of the human subject, changing the balance of the analysis towards a more symmetrical accounting for human and material agencies, and a move to examining the whole sociomaterial assemblage as the object of analysis.

6.3 Intentionality and the shaping of human agency

This is not to say that the human agent disappears from consideration in the examination of environmental management infrastructures. In our analysis, the EPA is not reduced to a passive bystander, an effect of other agencies. It is clear that the EPA played a leading role in orchestrating the emerging greywater management infrastructure. The particular accountabilities of the EPA as an environmental regulator (Pickering, 1995; Orlikowski, 2005; L. Suchman, 2007) led it to construct the goals that would bring about the intended extension of environmental management practice. It was the EPA's resources, skills and actions that set various nonhuman performances in motion or attempted to channel or control their agency (Pickering, 1995). The EPA had the power and legitimacy to both speak for and act to protect the environment through its institutional position in South Australia's environmental legislative framework. It had the resources to fund discursive and infrastructural development activity that ultimately aligned the interests of diverse stakeholders and produced the social and technical artifacts and their associated routines that formed the heart of the greywater management infrastructure.

However, the development of an environmental management infrastructure was not fully under the control of the EPA. Disciplined by the environmental regulatory regime in South Australia, it was not completely free to choose how to perform regulatory practice around greywater management. The discretion of its human agency was reduced. Established ideas of proper procedures and ways of acting within the EPA's own disciplinary practices as an environmental regulator shaped how it proceeded (Johnston et al., 2016) – assembling relevant knowledge of the greywater problem, engaging with its stakeholders, and manoeuvring within the environmental governance regime in South Australia. Similarly, the decision to use a relational database management system disciplined the development and form of the VMS to an extent as the specialised knowledge of information technology professionals was brought to bear on the emergent system.

The EPA was also active in identifying both limitations and possibilities in the emerging infrastructure as it continuously revised its short-term plans and goals while maintaining its mission to achieve environmental sustainability in the longer term. Its human agency did not proceed unchanged in the mangle of practice. Accommodations subjected its intentions to revision as it dealt with a variety of human and material resistances, ranging from the inertia of vessel owners reluctant to change established ways of handling greywater, mis-performing greywater treatment systems, or drought-induced low river levels. This was apparent in the perceived need to differentiate requirements based on the physical limitations of vessel size and the economic status of vessel owners, and the phased approach eventually adopted to implementing the greywater requirements of the CoP.

The social contours of the EPA's agency were transformed in the mangle of practice. The actions of other human actors were often significant, for example in setting high-level aims, highlighting concerns, or creating practical issues that needed to be overcome. The EPA needed to align the interests of these multiple, different organisations and actors as they interacted during the infrastructure construction processes. Acting as the legitimate 'spokesperson' for the environment, the EPA defined substantive criteria for what constituted greywater pollution and its associated risks. The development and promulgation of the CoP that materialised these criteria was the product of extensive negotiation with a range of stakeholders who wanted to be able to carry out boating-related activities on South Australia's waterways. While the CoP was a legally enforceable mechanism for protecting the aquatic environment from greywater pollution, it also allowed the activities that produce vessel greywater, by defining permissible ways for dealing with produced greywater.

These associations were constitutive of new relationships and roles in the boating industry in South Australia. The EPA's relationship with vessel owners and operators (and other related stakeholders) was formalised in specific terms in relation to vessel greywater management with the creation and performance of the artifacts and routines comprising the greywater management infrastructure. For example, vessel users were expected to comply with the regulatory agency of the CoP, to evidence compliance status or claims based on the data requirements of the VMS, and also to subject their vessels to monitoring via the EPA's audit routine. Similarly, the EPA developed relationships with other State entities, including Standards Australia, with whom it collaborated in the creation of a new a standard for acceptable greywater treatment. The EPA also extended its relationship with the Department of Transport in seeking to regulate greywater management practice for commercial vessels. This relationship was mediated via the 'load module' in the VMS and Department of Transport routines which subsequently informed the EPA. This coordination and alignment of the interests of different actors through the agency of social and technical artifacts is consistent with prior literature on infrastructure in other contexts (e.g., Venters et al., 2014).

6.4 Entangled artifacts and routines

We have suggested that artifacts and routines are the observable traces of the mangle in the extension of environmental management practice. Our analysis demonstrates how the routines and social and technical artifacts developed by the EPA were co-implicated in the emergence of the greywater management infrastructure. The EPA's agency was materially performed through artifacts, and these material performances were enacted by human agents in routines (Orlikowski, 2005). Each artifact, and its (re)configurations and adjustments contributed to reducing the instability brought forth by resistances in the evolving infrastructure through their performance in associated routines and practices. In turn, routines created through the exercise of human agency were modified through exposure to various material agencies in order to better perform vessel greywater management in practice.

When the EPA decided to develop a computer-based information system to facilitate monitoring of greywater management practice, the earlier alignments produced by the CoP artifact had to be fine-tuned. The material agency of the VMS became evident in how the properties of the relational database management system underlying the VMS allowed greater integration and consistency of the compliance data collected and maintained about vessels. The audit routine for monitoring compliance also developed in line with emergent refinements to the VMS as practical issues were encountered and accommodated in the evolving greywater management infrastructure. These included integration of the system with another regulator so as to capture data relating to commercial vessels, the needs of EPA audit staff for access to data in the field, and the actions of some vessel owners in circumventing the greywater treatment requirements of the CoP. While the performativity of the VMS in practice materially influenced the ongoing development of the vessel audit routine, the material form of the VMS was also itself at stake in these encounters.

Focusing on the entanglement of artifacts and routines is a helpful approach for tracing and analysing the process by which environmental management infrastructures are constituted and evolve over time. The ability of the EPA to discipline vessel users and shift their entrenched practices of handling greywater is a consequence of the particular relations between the artifacts it created and their performance in the audit routine with which they are associated. The effects of the greywater management infrastructure cannot be reduced to the separate effects of the CoP and VMS artifacts and the corresponding audit routine. Instead, they rely on the relative stability of their association in a specific, context-dependent configuration, itself the result of ongoing tuning in the mangle of practice. The emergent properties of the infrastructure are properties of the whole assemblage that would not exist if the individual parts were not assembled, organised and enacted in that particular way (Elder-Vass, 2007). The reconfiguration and extension of environmental management practice involves the creation and interactive stabilisation of new social and technical artifacts *and* the social relations and disciplined human performances that accompany them in routines and practices (Pickering, 1995).

7 Conclusion

Taking the position that environmental management is a sociomaterial practice, we have outlined a theoretical perspective that draws on some of the key ideas and concepts behind the ‘mangle of practice’ to account for the emergence of an infrastructure in the extension of practice to regulate vessel greywater management in South Australia. Our perspective explains how information systems underpinning environmental management infrastructures, together with other social and technical artifacts, are entangled with the routines in which they are enacted through ongoing interactions between human and material agencies. This mangling of practice is constitutive of change in environmental governance as certain actors such as environmental regulators seek to create associations between human and nonhuman entities, align their interests, and channel their agencies.

We have shown that human intentionality, in the form of the longer-term goal of the regulator, plays an important role in shaping the initial infrastructure, although pre-disciplined by established concepts and procedures entrenched in existing practice and vulnerable to revision in the short term. However, the exact form and destination of the infrastructure cannot be defined a priori. Instead, it emerges in practice over time as tensions and practical resistances arise in the intersection of different agencies that prompt actors to make accommodations on the path to that goal in a continual process of tuning. Equally, we have highlighted the centrality and material effects of nonhuman performances, both natural and artifactual, in this emergence. Focusing our analysis on the whole sociomaterial assemblage avoids reducing explanations of environmental change to human factors alone.

From a practical perspective, the emerging infrastructure, with regulatory artifacts, information systems and associated routines, is indicative of possible ways change in environmental management and sustainability can proceed. It suggests the need for an awareness by regulatory authorities and other actors involved of how the mangling of environmental management practice can constitute particular interactions between human agency and nonhuman performances, both in terms of the natural environment and the social and technical artifacts produced by those seeking to manage it. This offers the potential to identify opportunities for influencing the outcomes of such manglings, whether these are material transformations, changes in social roles and relations, or transformations in the concepts and knowledge informing practice. In the process, it may be possible to (re)shape the contours of environmental management practice and even shift the trajectory of future infrastructure development into a closer alignment with long-term sustainability goals.

For practitioners seeking to deploy information technology and systems in the service of environmental management, our research indicates the importance of understanding the historical context of change and the influence of past and current practices on their efforts. Rather than assuming a development trajectory exclusively driven by the agency of the developers, practitioners must be aware of the potential resistances arising from its intersection with a range of material and human agencies when the environmental information system is entangled in the practices and routines in which it is implemented.

Our analysis is based on an in-depth, longitudinal case study of a greywater management infrastructure developed by a South Australian environmental regulator. Our findings, though particular to the trajectory of this specific environmental management infrastructure, offer insights that can inform the analysis of infrastructures in other settings. For example, our analysis has identified two mangling episodes where key artifacts and routines emerged to regulate a particular sociomaterial practice and then informate the monitoring of that practice. Insights at this level may be transferable to other environment management infrastructures, under circumstances when regulatory authorities attempt to regulate human practices that are harmful to the natural environment. Our more detailed findings pertaining to the particularities of the greywater management infrastructure in our case study may need to be considered more carefully before they can be applied to other contexts. Overall, however, the broader posthumanist arguments about temporal emergence and performativity of practice underscore the importance of considering any infrastructure in its own right.

References

Abbott, O. (2016). Posthumanist perspectives and the Chernobyl disaster: Dances of agency, temporal emergence, and disaster risk management. *International Journal of Mass Emergencies and Disasters*, *34*(2), 231-249.

Australian Broadcasting Corporation. (2012, March 22). Boaties warned of greywater crackdown. *ABC Regional News*. Retrieved from Australia/New Zealand Reference Centre (EBSCO) on 6 May 2019.

Baker, L. R. (2004). The ontology of artifacts. *Philosophical Explorations*, *7*(2), 99-111.

Baygi, R. M., Introna, L. D., & Hultin, L. (2021). Everything flows: Studying continuous sociotechnological transformation in a fluid and dynamic digital world. *MIS Quarterly*, *45*(1), 423-452.

Brennan, B. (2013, January 16). Fifty shades of greywater. *The Murray Valley Standard*.

Retrieved from https://www.murrayvalleystandard.com.au/story/1238200/fifty-shades-of-greywater/

Burazin L. (2019). Law as an artifact. In M. Sellers, & S. Kirste (Eds) *Encyclopedia of the philosophy of law and social philosophy*. Dordrech: Springer. https://doi.org/10.1007/978-94-007-6730-0_217-1

Callon, M. (2007). What does it mean to say that economics is performative? In D. MacKenzie, F. Muniesa, & L. Siu, (Eds), *Do economists make markets? On the performativity of economics* (pp. 311-357). Princeton, NJ: Princeton University Press.

Chae, B., & Poole, M. S. (2005). The surface of emergence in systems development: Agency, institutions, and large-scale information systems. *European Journal of Information Systems*, *14*(1), 19-36.

Ciborra, C. U., & Hanseth, O. (2000). Introduction: From control to drift. In C. U. Ciborra Ciborra, K. Braa, A. Cordella, B. Dahlbom, A. Failla, O. Hanseth, V. Hepsø, J. Ljungberg, E. Monteiro, & K. A. Simon (Eds), *From control to drift: The dynamics of corporate information structures* (pp. 1-11). Oxford: Oxford University Press.

D'Adderio, L. (2011). Artifacts at the centre of routines: Performing the material turn in routines theory. *Journal of Institutional Economics, 7*(2), 197-230.

Department of Planning, Transport and Infrastructure. (2010, November 30). *Blackwater audits underway*. On Deck. Retrieved from

Department of Water, Land and Biodiversity Conservation. (2009). *River vessel waste disposal options: Edition no 2.*
Retrieved from https://www.epa.sa.gov.au/files/477475_riverboat.pdf

Edwards, P. N., Bowker, G. C., Jackson, S. J., & Williams, R. (2009). Introduction: An agenda for infrastructure studies. *Journal of the Association for Information Systems*, *10*(5), 364-374.

Elder-Vass, D. (2007). Luhmann and emergentism: Competing paradigms for social systems theory? *Philosophy of the Social Sciences, 37*(4), 408-432.

Elliot, S., & Webster, J. (2017). Special issue on empirical research on information systems addressing the challenges of environmental sustainability: An imperative for urgent action. *Information Systems Journal, 27*(4), 367-378.

Environment Protection Authority. (2001). *Environment Protection Authority annual report 2000–2001*. Retrieved from https://www.epa.sa.gov.au/files/8271_annualreport0001.pdf

Environment Protection Authority. (2002). *Environment Protection Authority annual report 2001–2002*. Retrieved from https://www.epa.sa.gov.au/files/8272_annualreport0102.pdf

Environment Protection Authority. (2003a). *State of the environment report for South Australia 2003*. Retrieved from https://www.epa.sa.gov.au/files/4771457_soe_index.pdf

Environment Protection Authority. (2003b). *Environment Protection (Water Quality) Policy 2003 and explanatory report*.
Retrieved from https://www.epa.sa.gov.au/files/477390_epwq_report.pdf

Environment Protection Authority. (2007a). *River Murray and Lower Lakes catchment risk assessment for water quality: Results and management options*. Retrieved from https://www.epa.sa.gov.au/files/8598_risk_2_s8.pdf

Environment Protection Authority. (2007b). Houseboat audits. *CE news* [External newsletter], November 2007, p. 2.
Retrieved from https://www.epa.sa.gov.au/files/4771761_ce_news_002.pdf

Environment Protection Authority. (2008a). *Code of practice for vessel and facility management (marine and inland waters)*. Adelaide: Environment Protection Authority.

Environment Protection Authority. (2008b, October 7). *New standard for greywater treatment*. [Media release]. Retrieved from https://www.epa.sa.gov.au/files/4771560_media209.pdf

Environment Protection Authority. (2009a, September 14). *New Australian standard now available for greywater treatment systems*. [Media release]. Adelaide: Environment Protection Authority.

Environment Protection Authority. (2009b, November 25). *Greywater deadline extensions for commercial river boats* [Media release]. Adelaide: Environment Protection Authority.

Environment Protection Authority. (2012a). *Strategic plan 2012-2015*. Retrieved from https://www.epa.sa.gov.au/files/4771468_strategic_1215.pdf

Environment Protection Authority. (2012b, March 16). *EPA launches compliance program for vessel wastewater*. [Media release].
Retrieved from https://www.epa.sa.gov.au/files/477894_media_16mar2012.pdf

Environment Protection Authority. (2015, June 12). *Houseboat greywater management audits*. [Media release].
Retrieved from https://www.epa.sa.gov.au/files/10911_media_12jun2015.pdf

Environment Protection Authority. (2019). *Environment protection legislation*. Retrieved from https://www.epa.sa.gov.au/data_and_publications/legislation

Eriksson, E., Auffarth, K., Henze, M., & Ledin, A. (2002). Characteristics of grey wastewater. *Urban Water, 4*, 85-104.

Faulkner, P., & Runde, J. (2019). Theorizing the digital object. *MIS Quarterly*, *43*(34), 1279-1302.

Gallagher, N., & Wigley, S. (2001). *Ecological impact of houseboats on the River Murray in South Australia*. Adelaide: Murray Darling Association Incorporated for Conservation and Sustainable Development.

Gaskin, J., Berente, N., Lyytinen, K., & Yoo, Y. (2014). Toward generalizable sociomaterial inquiry: A computational approach for zooming in and out of sociomaterial routines. *MIS Quarterly*, *38*(3), 849-871.

Harvey, P., Jensen, C. B., & Morita, A. (2017). Introduction: Infrastructural complications. In P. Harvey, C. B. Jensen, & A. Morita (Eds), *Infrastructures and social complexity: A companion* (pp. 1-22). Abingdon: Routledge.

Huvila, I. (2016). Awkwardness of becoming a boundary object: Mangle and materialities of reports, documentation data, and the archaeological work. *The Information Society*, *32*(4), 280-297.

Jean, D. (2012, May 25). EPA angers houseboat owners with waste threat. *The Advertiser*. Retrieved from https://www.adelaidenow.com.au/news/epa-angers-houseboat-owners-with-waste-threat/news-story/031ee85ecc6a8dd15ca5793f433bb555

Jenkin, T. A., Webster, J. & McShane, L. (2011). An agenda for 'Green' information technology and systems research. *Information and Organization*, *21*(1), 17-40.

Jensen, C. B. (2015). Experimenting with political materials: Environmental infrastructures and ontological transformations. *Distinktion: Scandinavian Journal of Social Theory*, *16*(1), 17-30.

Jensen, C. B., & Morita, A. (2015). Infrastructures as ontological experiments. *Engaging Science, Technology, and Society*, *1*, 81-87.

Jensen, C. B., & Morita, A. (2017). Introduction: Infrastructures as ontological experiments, *Ethnos*, *82*(4), 615-626

Johnston, R. B., Reimers, K., & Klein, S. (2016). Performing research validity: A "mangle of practice" approach. In L. Introna, D. Kavanagh, S. Kelly, W. Orlikowski, & S. Scott (Eds), *Beyond interpretivism? New encounters with technology and organization* (pp. 201-214). Cham, Switzerland: Springer.

Jones, M. (2014). A matter of life and death: Exploring conceptualizations of sociomateriality in the context of critical care. *MIS Quarterly*, *38*(3), 895-925.

Kallinikos, J. (2012). Form, function, and matter: Crossing the border of materiality. In P. M. Leonardi, B. A. Nardi, & J. Kallinikos (Eds), *Materiality and organizing: Social interaction in a technological world* (pp. 67-87). Oxford: Oxford University Press.

Kroes, P. (2010). Engineering and the dual nature of technical artefacts. *Cambridge Journal of Economics*, *34*(1), 51-62.

Leonardi, P. M. (2010). Digital materiality? How artifacts without matter, matter. *First Monday*, *15*(6). https://journals.uic.edu/ojs/index.php/fm/article/download/3036/2567

Leonardi, P. M. (2011). When flexible routines meet flexible technologies: Affordance, constraint, and the imbrication of human and material agencies. *MIS Quarterly*, *35*(1), 147-167.

Northwest Hydraulic Consultants. (2010). *Review of greywater management strategies to improve public health and water quality in Shuswap Lake*. Prepared for the Fraser Basin Council, Kamloops, BC. Retrieved from https://www.fraserbasin.bc.ca/_Library/TR_SLIPP/SLIPP_NHC_Greywater_Report_July2010.pdf

Orlikowski, W. J. (2005). Material works: Exploring the situated entanglement of technological performativity and human agency. *Scandinavian Journal of Information Systems*, *17*(1), 183–186.

Orlikowski, W. J. (2007). Sociomaterial practices: Exploring technology at work. *Organization Studies*, *28*(9), 1435-1448.

Pentland, B. T., & Feldman, M. S. (2008). Designing routines: on the folly of desiging artifacts, while hoping for patterns of action. *Information and Organization*, *18*(4), 235-250.

Pickering, A. (1995). *The mangle of practice: Time, agency and science*. Chicago: University of Chicago Press.

Pickering, A. (2008). New ontologies. In A. Pickering & K. Guzik (Eds), *The mangle in practice: Science, society, and becoming* (pp. 1-14). Durham and London: Duke University Press.

Pickering, A. (2013). Living in the material world. In F. X. de Vaujany & N. Mitev (Eds), *Materiality and space: Organizations, artefacts and practices* (pp. 25-40). London: Palgrave Macmillan.

Salter, C. (2001, January 12). Grey water ban? *Murray Valley Standard*. Retrieved from Infotrac Newsstand on 8 May 2019.

Sandberg, J., & Tsoukas, H. (2011). Grasping the logic of practice: Theorizing through practical rationality. *Academy of Management Review*, *36*(2), 338-360.

Seidel, S., Recker, J., & vom Brocke, J. (2013). Sensemaking and sustainable practicing: Functional affordances of information systems in green transformations. *MIS Quarterly*, *37*(4), 1275-1299.

Singh, M. & Sahu, G. P. (2020). Towards adoption of Green IS: A literature review using classification methodology. *International Journal of Information Management*, *54*, Article ID: 102147.

Spencer, J. (2011). 2011 River Murray risk assessment. *The Rambler, 29*(4): 1, 7. River Murray Boat Owners Association.

Standards Australia. (2009). Greywater and the SA EPA. *Standards Australia bulletin*, #2_10 September 2009, p. 1. Retrieved from https://www.standards.org.au/StandardAU/Media/SA-Archive/ OurOrganisation/News/Documents/Bulletin_2_Standards_Australia_100909.pdf

Star, S. L. (1999). The ethnography of infrastructure. *American Behavioral Scientist, 43*(3), 377-399.

Suchman, L. (2007). *Human-Machine Reconfigurations: Plans and Situated Actions* (2nd ed.). Cambridge: Cambridge University Press.

Suchman, M. C. (2003). The contract as social artifact. *Law & Society Review, 37*(1), 91-142.

Symon, G., & Pritchard, K. (2015). Performing the responsive and committed employee through the sociomaterial mangle of connection. *Organization Studies*, *36*(2), 241-263.

United Nations. (2018). *The sustainable development goals report 2018*. Retrieved from https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf

Venters, W., Oborn, E., & Barrett, M. (2014). A trichordal temporal approach to digital coordination: The sociomaterial mangling of the CERN grid. *MIS Quarterly, 38*(3), 927-949.

Verbeek, P. P., & Vermaas, P. E. (2009). Technological artifacts. In J.K. Berg Olsen, S.A. Pedersen, & V. Hendricks (Eds.), *A Companion to the Philosophy of Technology* (pp. 165-171). West-Sussex, UK: Blackwell.

Walsham, G. (1995). Interpretive case studies in IS research: nature and method. *European Journal of Information Systems, 4*(2), 74-81.

Williams, R., & Pollock, N. (2012). Moving beyond the single site implementation study: How (and why) we should study the biography of packaged enterprise solutions. *Information Systems Research*, *23*(1), 1-22.

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