www.water-alternatives.org Volume 11 | Issue 2

Beck, M.B.; Thompson, M.; Gyawali, D.; Langan, S. and Linnerooth-Bayer, J. 2018.
Viewpoint – Pouring money down the drain: Can we break
the habit by reconceiving wastes as resources?
Water Alternatives 11(2): 260-283

Viewpoint – Pouring Money Down the Drain: Can We Break the Habit by Reconceiving Wastes as Resources?

Michael Bruce Beck

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; and Department of Civil and Environmental Engineering, Imperial College, London, UK; mbrucebeck@gmail.com

Michael Thompson

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; and Institute for Science Innovation and Society (InSIS), University of Oxford, UK; thompson@iiasa.ac.at

Dipak Gyawali

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; and Academician (Pragya), Nepal Academy of Science and Technology; dipakgyawali.dg@gmail.com

Simon Langan

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; langan@iiasa.ac.at

JoAnne Linnerooth-Bayer

International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria; bayer@iiasa.ac.at

ABSTRACT: As water-sector professionals re-discover the value in the 'waste' conveyed in 'waste'water, this Viewpoint argues that the theory of plural rationality (also known as Cultural Theory) may accelerate the switch from waste management to resource recovery. Accordingly, it extends the framing of plural rationality, from its traditional applications in matters of governance and social and economic analysis, to the beginnings of a set of plural schools of engineering thought. This sounds controversial. Indeed, we hope it is. For all too often ways to resolve water issues end up in the impasse of two deeply entrenched positions: the 'technocratic reductionism' of the 'quick engineering fix' to problem solving; and the 'participatory holism' of the 'local, socially sensitive, integrationist' approach. Plural rationality sees this is an impoverished duopoly. Our very strong preference is to find ways of promoting the *creative interplay* among plural (more than two), mutually opposed, contending ways of framing a problem and resolving it. This, we argue, should not only expand the portfolio of possible alternatives for technology-policy interventions, but also lead to the chosen alternative being preferable — in social, economic, and environmental terms — to what might otherwise have happened. Such solutions are called 'clumsy' in plural rationality theory. We use a synopsis of a case history of restoring water quality in the River Rhine in Europe, within a wider account of the sweep of resource recovery spanning two centuries (late 18th Century through early 21st Century), to illustrate how clumsiness works. This, however, does not extend to our elaborating our proposed set of plural schools of engineering thought beyond just its very beginnings. Our Viewpoint allows us merely to start framing the challenge of developing, and eventually applying, such a notion.

KEYWORDS: Circular economy, clumsiness, Cultural Theory, lock-in, nutrient recovery, plural rationality, plural schools of engineering thought, Rhine restoration, technological invention and innovation, urban metabolism

IDEAS WHOSE TIMES HAVE COME?

They say it takes at least 20 years for a good idea to come to fruition. If so, then policy and technological innovation for managing water quality may be entering a phase of perhaps profound change, one brought about by the conjunction of *two* good ideas whose time may truly have come: resource recovery from 'waste' flows of water; and clumsiness, as opposed to elegance, in the affairs and systems of governance. In Section 2, we shall begin with the latter, not least because of its strange labelling and not least too because it is the primary framing of this Viewpoint. In a nutshell, our Viewpoint entails a theory: a way of seeing things that pushes outside and beyond conventional duopolies, often played out (or more likely not) as the impasses of highly fractious opposition. Familiar examples of these duopolies are those between free-wheeling entrepreneurial, private enterprise and government regulation, or between the 'reductionist quick engineering fix' and the 'holistic socially sensitive' approaches to, say, water security (witness Zeitoun et al., 2016).

This primary framing of the Viewpoint of Section 2 is then used to develop a second vital extension of it: a set of plural schools of engineering thought, which has the potential to enhance the variety and creativity of technological innovations for achieving *non*-water resource recovery in the water sector. This second important element of our Viewpoint is developed across Section 3 of the paper. Ostensibly, Section 3 is an historical account of the fall and rise of such resource recovery over two centuries. For the entire 20th century the prevailing view was that those (non-water) resources were in fact pollutants to be controlled and eliminated. Restoration of water quality in the River Rhine in Europe and in the Great Lakes of North America are the iconic successes of doing precisely that. The history of both, as it happens, has been the subject of analysis through the very same primary lens as that of this Viewpoint: the theory of plural rationality, also known as Cultural Theory (Thompson et al., 1990). And there continue to be important lessons to be learned today, in countries of the Global South struggling with just such problems, as they cope with modernity in a variety of quite different institutional settings. By way of introduction, therefore, it is enlightening to recount here one of those histories (that of the Rhine). In this we are summarising the work of Verweij (2000, 2011, 2017).

Verweij's analysis looks back to the 1960s and ends, in effect, with the success of the Rhine Action Programme (RAP) by the close of the 1990s. One could say there was an elegant but unsuccessful 'before' the Sandoz spill of 1 November, 1986, and a clumsy but successful 'after'. In the couple of decades prior to Sandoz, governance for controlling water pollution (at the supra-national level) could be described as having been predominantly, if not overwhelmingly, *hierarchical* in character: it was all about command-and-control – just a single overly elegant style of problem framing and problem solving. The behaviour of the *individualist* private-sector chemical industries along the Rhine was to be made compliant with the controls of public-sector government edicts. Indeed, and tellingly for this paper, Verweij notes that these industries became much better at complying once they were freed from the strictures of implementing only government-approved prescriptions of 'best available technologies'.

After Sandoz, plural voices had access to (and were granted respect at) the table of debate. Government agencies were joined there by *egalitarian* community-activist, non-governmental organisations, while part-egalitarian, part-individualist water utilities bore down on the chemical industries with a combination of carrots and sticks. The result was that these industries went above and beyond the basics of compliance, not only to clean up their own effluent discharges, but to sell profitably to others the new technologies of wastewater treatment they had developed under the driver of achieving compliance. Overlain on top of this, the instincts of the egalitarian activist stakeholders were being realised in a progressive 're-naturalising' of the Rhine watershed. All in all, plural rationalities were entertained and permitted to thrive within the context of governance for water quality management. They were the plural caricatures of the characteristic styles of policy-making we have labelled hierarchical, egalitarian, and individualist. Such a form of governance was anything but elegant; it was clumsy, hence the deliberate use of this word (Verweij and Thompson, 2006).

For all the many merits of Verweij's work, however, we should remind ourselves of this. It was a retrospective analysis of contaminant (resource) elimination, not a sparking of the prospective shift we are seeking, to resource recovery and management. And that, the second good idea whose time has hopefully come, will be much more familiar to readers of this journal. Nevertheless, while resource recovery has re-emerged into the light of day, it has struggled to do so (as Section 3 records). Indeed, the language we use is revealing. Urban 'water resource centres', which is how wastewater treatment plants have come to be conceived of today, were once known as sewage farms. Yet under the pressure and urgency of pollution control over the past 70 years or so, the beneficially productive element associated with the idea of a farm has become substantially obscured (albeit not entirely lost, but pushed progressively into the background). For as long as one conceives of wastewater as impure, contaminated water, policy and technology interventions will emphasise the value of the water and the non-value of the 'waste'. Hence, the existence of today's 21st century water resource centres.

And yet, there *is* value in the materials entrained into the urban water metabolism. We estimate there is a global market for nutrient resources recovered from municipal sewage of some $65B (Villarroel Walker and Beck, 2014). Indeed, when this figure is combined with the comparable figure for nutrient resources recoverable from agricultural activities ($235B), the two add up to a total (coincidentally) identical to what Trucost (2013) estimates to be the unaccounted-for externalities attaching to eutrophication (i.e. pollution resulting from the discharge of excessive amounts of nutrients into the aquatic environment).[1] Clearly, then, there is a *prima facie* case for not pouring the costs of operating wastewater treatment systems down the drain of this public-good infrastructure, but of facilitating access to the wherewithal to build up the business of recovering the private goods embodied in the recovered nutrients and other chemicals. Except that one might then ask, if each and every one of us has bought the food we eat in the first place, who 'owns' the resulting nutrient metabolic by-products?

More immediately, this Viewpoint poses the following core question:

> How can we organise our thinking and concepts in a systematic manner, to address issues in the natural, human, *and* built environments, with a view to breaking out of the confines of the predominant contemporary conceptual framing of water pollution control and the social and physical 'lock-in' that accompanies it?

Here we take the 'built environment' to be that segment of infrastructure, technical devices, and technical practices that mediates the relationship between man (human environment) and nature (natural aquatic environment). Thus, just as the built environment mediates the relationship between man and nature in respect of the city, so too it mediates the relationship between the likes of confined animal feeding operations (CAFOs) and nature in the rural landscape.

Our ultimate destination in the present paper, at the close of Section 3, is the expression of a set of plural schools of engineering thought: thinking, that is, about how to structure the built environment and, in particular, about how technical and technological innovation occur. The foundations and pillars required to support such a construction – the theory of plural rationality itself, presented in a manner tailored to the particulars of water pollution control and resource management – constitute the subject of Section 2.

---

[1] To be precise, the agricultural figure is closely associated with 'wastes' emanating from intensive livestock production in what are sometimes referred to as Confined Animal Feeding Operations (CAFOs). By reflection, and while perhaps not all that complimentary about life in the city, we may think of cities as places of Confined Human Feeding Operations, or CHFOs.

We do not presume either the time or the space (in this article) to respond adequately to our overarching question. For again, lest we forget, these are very early days, not only in making the change from waste disposal to resource recovery, but also simply in crafting the outlines of the set of plural schools of engineering thought. Which latter is itself a far cry from then seeing the schools of thought applied in practice, effectively and on a broad scale. Accordingly, our concluding Section 4 will close with the brief expression of two consequent further challenges.

CONCEPTUAL FRAMING: PLURAL RATIONALITY AND CLUMSINESS

Our Viewpoint will necessarily cover the gamut: of how plural rationality (Thompson et al., 1990) provides a way of thinking about social goods, schools of economic thought, enterprise risk management, stability and resilience in the natural and human environments, deliberative quality in governance, and perhaps surprisingly – but most importantly – plural schools of engineering thought. To begin, we must get down to the basics (albeit briefly) of how elegance in determining policy-technology interventions in the water sector differs from clumsiness. Needless to say, for a subject with its roots in the 1960s – tellingly, in anthropologist Mary Douglas's *Purity and Danger: An analysis of concepts of pollution* (Douglas, 1966) – there is a very great deal more that could be said of the theory of plural rationality than the mere 'headlines' that follow. They are necessarily selective and focused on the specific needs of the present paper (for fuller accounts, see, for example, Thompson et al., 1990; Verweij and Thompson, 2006, and Thompson, 2008).

In short, almost all of our Viewpoint can be condensed down into Figure 1, which we shall assemble bit by bit as our argument proceeds, building up from the base of each of its quadrants. Indeed, we shall be composing Figure 1 across both the current section and Section 3 below. Accordingly, the entries in each quadrant *below* the (emboldened) title of the given quadrant represent collectively the layers in the 'platform' of the first facet of our Viewpoint, i.e. the significant, relevant elements of the theory of plural rationality (as introduced in the present section). Then, upon this platform, we shall build out the second facet of our Viewpoint across Section 3, i.e. the plural schools of engineering thought, with their entries for each respective school set *above* the title of the given quadrant.

Elegance, clumsiness, and deliberative quality in governance

Clumsiness – the term is deliberately tongue-in-cheek – challenges the orthodoxy, which we call elegance. This orthodoxy is enshrined in the four precepts of policy analysis: first, establish a single and agreed definition of the problem; second, clearly distinguish facts from values; third, set up a 'single metric' (almost always dollars) so as to be able to compare and evaluate alternatives; and, fourth, optimise around the best of those options. In our view, these precepts of elegance are appropriate only for problems, such as here, of designing a pollution-control facility at least cost to ensure compliance with clearly expressed effluent-discharge standards. For such problems, the heights of elegance – or equivalently, the depths of deliberative quality – are attained when one particular agency, group, stakeholder, or actor frames the problem; frames it moreover in a way perfectly suited to its traditional, conventional, standard means of problem-solving; and takes no heed of any other style of problem-specifying and problem-solving. The pre-Sandoz agenda for restoring the quality of waters in the Rhine could be described as just such an elegant state of affairs, especially before the (hierarchical) government agencies relinquished their insistence on prescribing what *they* deemed to be the 'best' available technology. In terms of deliberative quality, elegance aligns closely with what is called a closed hegemony (Ney, 2009): there is but the one way of perceiving the world and acting in it; but the one rationality prevails. Only one stakeholder sits at the metaphorical table of debate; in fact, no debate takes place.

The heights of clumsiness are quite the opposite. They align with political theorist Dahl's 'pluralist democracy', or rather, its refurbishment by Ney (2009) according to the principles of Cultural Theory

(Thompson et al., 1990). To attain these heights, plural rationalities – plural ways of seeing the world and acting in it – must be sustained; and the more of them, so much the better, up to a point (of four, possibly five, rationalities, as we shall shortly see). Deliberative quality is elevated because plural 'voices' are admitted to the table of debate (and noisy and contentious it may well be), each being heard by the others and responded to, not dismissed by them. Such was the case, Verweij (2011) argues, in the post-Sandoz era of the Rhine Action Programme. The hierarchical, public-sector government agencies had a voice, as did the egalitarian community activists, along with the individualist private-sector chemical industries and the part-egalitarian, part-hierarchical water utilities.

Expressed in familiar terms, this is the stark difference between elegance and clumsiness. In the former, the one 'solidarity' (the predominant stakeholder-voice) frames the problem to suit its problem-solving talents, which it imposes on the other solidarities-stakeholders and, shouting them down, 'goes it alone'. The sole rationality seeks to "get what it alone wants". In clumsiness:

> *Each* solidarity "gets more of what it wants, and less of what it doesn’t want, than it would have got, had it gone it alone".

Clumsiness will be found, therefore, in none of the three possible closed hegemonies. For while it is highly tempting to suppose it is always the hierarchical position that imposes a closed hegemony (epitomised in the military soubriquet of 'command and control', against which all can now rail), each solidarity is fully capable of it.

For example, during the 1980s the European Commission (now the EU) saw the UK position on water pollution as something of a closed individualist hegemony: the steadfast intent to "Keep on polluting until the environment shouts back 'Ouch!'" [Beck (1985) observing upon Haigh (1984)]. To be somewhat less crude, the then UK position was more probably individualistic only in the context of marine pollution (and why should it not take comparative economic advantage of its geographical position, when other countries take advantage of theirs?). It was a customary hierarchical hegemony in respect of pollution of inland waterways: determined by the 5-day presumed travel time of river flows to the sea, which became enshrined in the eponymous 5-day biochemical oxygen demand (BOD) test for gauging pollutant concentrations, by which to size and design wastewater treatment capacities. If effluents were discharged at a location with zero days travel time to the sea, then (the individualists would argue) mere natural 'dilution should be the solution to pollution'.

At about the same time, and again by way of illustration, an egalitarian closed hegemony was emerging from behind the EC 'black lists' of toxic and hazardous pollutants. It gave rise to the precautionary principle: of do no harm to the environment unless the absence of harm from the proposed action can be (very) convincingly demonstrated.

To summarise, clumsiness is the capacity to acknowledge and to benefit from plural, contending, mutually opposed ways of seeing the world and acting in it. The plural rationalities may be 'naturally' present within the already emerging contestation and disputes about the 'right' way to frame and solve a problem; or they may be capable of being reasonably contrived and constructed according to the theory, hence pitched anew into the debate. Whatever is the case, we argue that by recognising them *in their plurality* any set of water alternatives will be markedly enriched thereby (here, in respect of pollution control and resource recovery).

Stability, risk and resilience – in the natural and human environments

So far, we have introduced three of the rationalities and referred to them as hierarchical, individualist, and egalitarian. How each looks upon the world in profoundly different ways is implicit in what has already been said. This now needs to be brought to the surface and expressed both more clearly and in a little more detail. We may begin to construct Figure 1 (though not necessarily in the customary, logical order of draftsmanship).

Figure 1. The typology of the theory of plural rationality.

Asymmetrical Relationships ↑ – – – No Science; No Learning Innovation by Utterly Pure Chance ENGINEERING **– – FATALISM – –** Excluded from Club Goods of Others RISK ABSORBING Deliberate Forgetting/Ignorance What Models? UNKNOWN KNOWNS Randomness: Neither Stability Nor Instability NATURE CAPRICIOUS ← *Individualized*	↑*Asymmetrical Relationships* Nature to Match Man Man to be Less Bad Hands-on Technocratic Control Reductionist Science Technology: 'Big is Best' ENGINEERING **– – HIERARCHY – –** Investing in Public Goods RISK MANAGING Diffident about Future: Future ≠ Past Trust Models KNOWN UNKNOWNS Conditional Stability NATURE TOLERANT BUT PERVERSE *Grouped* →
← *Individualized* – Man to be More Good Exuberant, Competitive Trial and Error Whatever Science Technology: 'Cheap and Cheerful' ENGINEERING **– – INDIVIDUALISM – –** Investing in Private Goods RISK SEEKING Confident about Future: Future = Past Trust Models KNOWN KNOWNS Unconditional Stability NATURE BENIGN *Symmetrical Relationships* ↓	*Grouped* → Man to Match Nature Man to be Less Bad Hands-off, Self-organising, Nature-centric Holistic Science Technology: 'Small is Beautiful' ENGINEERING **– – EGALITARIANISM – –** Investing in Common-pool Goods RISK AVOIDING Diffident about Future: Future ≠ Past Distrust Models UNKNOWN UNKNOWNS Unconditional Instability NATURE EPHEMERAL ↓*Symmetrical Relationships*

Note that the logic in sequencing the entries in this figure is built up from the base of each of its quadrants, with the principal title of each quadrant separating the arguments of Sections 2 (below title) and 3 (above title). One of the axes spans the continuum of symmetric-asymmetric relations, by which we mean, for example "you scratch my back, I'll scratch yours" (symmetry), as opposed to what is said of society in Boston, Massachusetts, where "Lowells speak only to Cabots and Cabots speak only to God" (asymmetry). The other axis spans the continuum of individualised-grouped outlooks, as illustrated by Groucho Marx, for example, who would not join any club that would have him as a member (individualised), which can be juxtaposed with the behaviour of someone who becomes a member of a monastic community (grouped). Although the role of computational models is only touched upon in passing in this Viewpoint, the attitudes of each rationality towards them is revealing. In contrast to the three other positions, members of the Fatalist camp have no grasp of how the world works. They are incapable of learning; "What Models?" they therefore wonder. For its part, Egalitarianism distrusts models intensely. What will be important in the future are events that are profoundly different from anything ever observed in the past, hence quite unpredictable by any model. In complete contrast, Individualism invests unquestioning, deterministic-like trust in any model and holds that the future will in any case be essentially like the past ('Future = Past'). Hierarchy holds the balance between Individualism and Egalitarianism. Experts will surely be able to establish those bounds beyond which disturbance to the environment may provoke disastrous consequences.

The easiest point of entry is from those perspectives most familiar to us (although they would not necessarily have been referred to as individualist, hierarchical, or egalitarian). Let us begin with the individualist outlook. This position holds that 'Nature is Benign', one of the five Myths of Nature introduced by systems ecologist Holling (1977, 1978). It is the caricatured outlook of those who would "Keep on polluting until the environment shouts back 'Ouch!'". No matter the size or character of the disturbance of the system – a lake, the economy, the climate – the system returns to the natural equilibrium we have come to know and love. The dynamic behaviour of the system is inherently stable. In the financial world, the behaviour of the market is such as to favour and promote the seeking out and taking of risks, since having the bet fail looks quite improbable. Those who subscribe, then, to the profit-maximising individualist point of view are *risk-seeking* types. Their belief is that there are solely 'known knowns' in the world. The individualist outlook appears in the lower left quadrant of Figure 1.

In sharp contrast and opposition to the individualist stance, the egalitarian (in the lower right quadrant of Figure 1) believes that 'Nature is Ephemeral', precariously stable, ever on the brink of collapse. The precautionary principle is redolent of this position. But the merest tick of a perturbation in the system – but a smidgen of black-listed toxicant released into a water body – will cause things to crash off and out into disaster. Egalitarian investors will hold those dastardly risk-seeking individualists utterly responsible for inducing the boom in the market that inevitably, as they know so well, can only but lead to bust: the market collapse touched off, in the end, by some barely noticed adverse gust of economic wind that was bound (the egalitarians would say) to happen sooner or later. The egalitarian camp is *risk avoiding*. It occupies the quadrant (in Figure 1) of the unknown unknowns. Persons with this kind of egalitarian creativity and imagination are invaluable to so-called 'emerging risk' committees in business.

Holding the balance, as it were, between the two polar opposites of the individualist and egalitarian solidarities, are members of the hierarchical persuasion: 'Nature is Tolerant But Perverse' (upper right quadrant, Figure 1). Things are conditionally stable. Provided the system is not struck by too great an adverse disturbance, its behaviour will return to the familiar equilibrium. Beyond a certain bound, however, disturbance will be sufficient to bar the system from recovery and instead induce collapse – behaviour will have been pushed beyond one of those famous 'tipping points'. Importantly, the view is that science and technical understanding of the system's behaviour will allow hierarchical adherents to determine those boundaries beyond which society should fear to tread. Thus it is that the hierarchical position is so naturally associated with effluent and environmental standards and the knowledge base historically underpinning the 5-day BOD test. Those of the hierarchical persuasion neither zealously seek out risk nor shrink before the prospect of the merest hazard; they are *risk managing* in their attitude towards risk. To their position can be credited the origins of enterprise risk management (ERM) in business. Their 'season' of risk, so to speak, is neither boom nor bust, but something clearly in between: a moderate regime of risk exposures, with a consistent upward trend in markets and economic performance. Nonetheless, they acknowledge that there are known unknowns.

Given now three of the four combinations of 'known' and 'unknown', the existence of a fourth rationality, that associated with the unknown knowns (upper left quadrant, Figure 1), should be unsurprising. The theory of plural rationality calls it *fatalism*; its myth is that of 'Nature Capricious'. The system is buffeted about in any and every which way as it responds to this or that disturbance. Affairs are ever between stability and instability, neither one thing nor the other. Indeed, nothing at all makes any sense in the world of the fatalist, including taking any purposeful action. Why bother to vote, the government always gets in. Fatalists are the *risk absorbers*, the 'dumpees', who are always being dumped upon. But this fatalist outlook is different from each of the other three in at least one significant way. A predominance of fatalists does not constitute a closed hegemony, since theoretically the fatalist perspective musters no problem-solving procedure, even if it cared to specify a problem in the first place, which it does not. Indeed, fatalist and solidarity barely go together, by definition. The fatalist is incapable of grasping what the problem might be; the world behaves with neither rhyme nor reason. Fatalists do not seek to have even a seat, let alone a voice, at the table of debate. So in the grand scheme of things, what purpose *does* the fatalist solidarity serve? Oddly enough, there are several:

(i) First, if the swelling of the fatalist ranks can (somehow) be detected, this signals that deliberative quality and clumsiness in governance are being eroded, hence in need of remediation. In fact, a progressive drift of persons from other camps into that of the fatalists – the process of their *fatalisation*, that is – may be especially important (as evident under the third beneficial use of fatalism below).

(ii) Second, if nothing can be done about a problem, then there is wisdom and experience to be had in not wasting time and money trying to fix the unfixable. The fatalist position was absent from Verweij's (2011) account of the Rhine case history, but it was present in the companion case history of the Great Lakes (Verweij, 2000). The best that should be done with the contaminated sediments at the bottom of Lake Erie is to leave them untouched and to trust they will, over time, become buried and immobilised by further natural sedimentation. In the financial world, there are times when (to corrupt the familiar invocation to act) there is considerable merit in 'just standing there and doing nothing'. Such a fatalist strategy is empirically apparent in the behaviour of asset managers in insurance companies. It is tailor made for those kinds of prevailing risk exposures when the market is not in a state of boom, or bust, or moderate, but in what has been called the 'uncertain' season of risk, when price fluctuations amount basically to white noise (Ingram and Thompson, 2011).

(iii) Third, and yet another insight from business and finance, a recent study of risk attaching to the use of computational models was obliged to categorise a fourth style of decision-making: for those, that is, who hold there are known unknowns. In public, it was dubbed that of the 'intuitive decision maker' (Tsanakas et al., 2014; Aggarwal et al., 2015).[2] In private, it was known as that of the cynical: the kind of behaviour in which the empirical data are manipulated retrospectively to justify past flawed decisions. In the restoration of water quality in the Rhine, a fatalised hierarchical position would have been to insist (perhaps by any means) that the best available technology continued to be the best, regardless of all its past demonstrable failures – demonstrable in the eyes of everyone else, that would be – to deliver what had been promised.

Over the years, elaboration of the constructive role of the fatalist position has been somewhat neglected. More recently, this oversight has begun to be redressed. There is the view that fatalised positions may be acting as very significant barriers to innovation, especially in breaking out of historic technological lock-ins (Thompson and Beck, 2017). And that, to follow on from this Viewpoint (and into our future research), may be crucial to developing policy alternatives for curbing water pollution while shifting towards resource recovery.

If the fatalist solidarity has been inadequately addressed in the past, the same (and more so) can be said of what is still a somewhat puzzling fifth solidarity: that of *autonomy*, or alternatively of the *hermit*, whose myth is one of 'Nature (supremely) Resilient'. Thus, the hermit's outlook on the world includes elements from each of the perspectives of the other four, yet is distanced and disengaged from them. This distancing propels the hermit's position to the very centre of Figure 1. It is omitted, however, for reasons of capping any further cluttering of Figure 1 and because its interpretation requires a subtle appreciation of a complex system's dynamic behaviour (see, for example, Thompson, 2008: 42-49).

[2] At a conceptual 'systems' level, there are close parallels between how we think about environmental protection (as here) and financial protection (as in Aggarwal et al., 2015).

Again, to take stock of all of this – for the purposes of reconsidering waste and resource management in the water sector – the four (five) ways of seeing the world and acting in it entail social constructions of nature. Crucially, what holds for Holling's Myths of Nature has been shown to map (one-to-one) from the study of ecological systems in the natural environment across to the study of anthropological and social systems in the human environment (Thompson, 2002; also Thompson, 2008). In other words, the nub of our Viewpoint has to do with exploring how we are to get along with each other and how we are to live with nature. What motivated Holling was originally, and in very large part, the search for an understanding of resilience, the peak of which became manifest in the hermit's myth. These heights of resilience in the behaviour of the natural environment correspond to the heights of deliberative quality, *ergo* clumsiness, in governance. That is the significance of the myth of the hermit herein. And clumsiness, we argue in this Viewpoint, is profoundly important to diversity and resilience in the formation of policy and the sparking of technological innovation in the strategic shift we seek, from waste to resource management. Put another way, clumsiness embraces the virtue of touching upon as widely divergent plural bases as possible before going ahead with a candidate decision, policy, or technological intervention, not just the one base alone – not just the one way of problem framing and problem solving. Put another way, the intent of clumsiness is to puncture 'group think'.

Social and economic goods

Both economists and political scientists have long recognised a typology of four kinds of goods: *private*, *public*, *common-pool*, and *club*; each cited once, in its own particular way, in the four quadrants of Figure 1. That there are these four kinds of goods does not sit comfortably with the similarly long-recognised distinction (among social scientists generally) of just two ways of organising, *markets* and *hierarchies*, onto which map respectively private goods and public goods. The two were prominent in the pre-Sandoz decades of the Rhine restoration case study. Hierarchical government agencies were seeking to build up the public goods of water and wastewater infrastructure, along with lowering society's propensity to pollute the natural environment. The individualistic chemical industries along the Rhine were self-evidently interested in profiting from building up private goods, while continuing to be as little fettered by government regulations as possible, including in respect of their releases of pollutants to the environment. This was the familiar and classical duopoly. And while it entailed some restoration of the accumulated deficit of the Rhine's natural capital (a kind of 'business speak' not employed at the time), its social and economic transactions were not primarily or directly addressed to building up this common-pool good, as any then active egalitarians would have wanted to see. For they, and their commitment to common-pool goods, were absent from the duopoly. Absent too, unsurprisingly, and likewise absent from Verweij's Rhine analysis, was the fatalist solidarity, with its exclusion from any club goods being built up by the others.

Essentially, however, and this is our point, the classical binary split of private and public goods (of markets and hierarchies) is insufficiently plural.

In the pre-Sandoz era, this duopoly was played out primarily for the benefit of society and its economy – some enhanced 'getting along with one another', in other words. Society had sensed that the Rhine River had, after being subjected to decades of persistent stress, shouted back "Ouch"! Penalties to society were due, with penalties being very much the thing for adherents of hierarchy. The excesses hitherto of the free-wheeling market players were to be reined in. They were; and the Rhine had recovered, to some extent. But then came the Sandoz spill in 1986 with its devastation of the river's flora and fauna.

The argument could have been made (and it had been made; Beck, 1981) that, if this disastrous event had killed untold numbers of fish, then this was because the fish were there precisely because they had been brought back by the restorative actions of the duopoly in the immediately preceding decades. Fish need a minimum amount of dissolved oxygen (DO) for their survival. Removing the steady, chronic, persistent stress on the river's DO resources by removing the polluting BOD during wastewater treatment generally elevates the river's average level of DO. If fish proliferate and prosper as a consequence, and if the general public becomes increasingly aware and appreciative of this social, public or common-pool good – the presence of the fish, when contrasted with their absence in living memory – the public outcry at their mass demise will be so very much all the greater. In short, lifting off the persistent, steady, average level of stress serves to emphasise the significance of the fast, transient shock, which previously would have passed unnoticed (Beck, 1981, 2005). After all, what is the significance of yet another insult, when the river is already 'dead'?

Yet 'living with nature' calls for something more than what the duopoly was delivering by way of some enhancements to our 'getting along with one another', i.e. enhancements to just our social and economic goods.

In the post-Sandoz era, Verweij (2011) writes of the emergence and impact of the egalitarian solidarity, with its motivation to build up common-pool goods, in particular, the regrowing back up of natural capital out of its massive historical deficit. This came in the form of righting the past wrongs of man's engineering interventions by way of *inter alia* historic river canalisation. The egalitarian 're-engineering' amounted to the re-naturalisation of the river. It was a spatial rearrangement of the river and watershed, which, in a *passive* sense, doubtless enabled certain previous distortions in the river's temporal hydrological spectrum to be remedied. Today, such passive spectrum restoration has its *active* counterparts. They are ones made available to us by those very civil engineering interventions (dams-impoundments, as in Richter et al. (2006); urban wastewater infrastructure, as in Beck (2011)) that brought about the damaging distortions of the hydrological spectrum in the first place – distortions, that is, resulting from serving the predominant frequencies of the 24-7 routine of modern economies and the socio-economic life of cities. What is more, these active counterparts can be deployed in ways that reconstruct the spectrum not only of mere hydrology (flows) but also of variations over time in nutrient availability (Beck, 2011; Beck et al., 2010). Indeed, our contemporary business speak has taken us beyond social, economic, and natural goods, beyond even natural capital, to embrace the idea of ecosystem services and ecosystem service providers (Beck, 2011, 2016).

Still, the fate of the fatalist solidarity remains both unexplored and unexploited. Besides we have now strayed away from the notion of economic goods and into the domain of engineering and technology.

Thus, to summarise the development of our argument up to this point, the key elements of the theory of plural rationality – the first facet of our Viewpoint – have been introduced. They are the entries in the lower halves of each of the quadrants in Figure 1. Our argument was built up from the foundational basis of the Myths of Nature, with their attaching caricatures of stability and resilience in the natural environment. It was then mapped across to the human environment, passing through the various combinations of 'knowns' and 'unknowns', up to business-oriented attitudes towards risk and forms of goods, and on to the four social solidarities of plural rationality: the emboldened titles of each quadrant in Figure 1. Looking back, the plural rationalities of those four solidarities enabled us to open this Section 2 by drawing the distinction between clumsiness and elegance in problem-solving. We pointed there to the depths and heights of deliberative quality in governance and decision-making.

From this basis of plural rationality in the natural and human environment, we shall shortly proceed (in Section 3) to developing the second facet of our Viewpoint: expression of our nascent concept of a set of plural schools of engineering thought. And that is something cast within the domain of problem-solving for the built environment. But first, there are some preparatory questions to ask, in the light now of what has so far been presented.

The built environment: Engineering, technology and infrastructure

Are we today still suffering from a closed hierarchical hegemony of hierarchical prescriptions of best available technologies? Where now are the sources of individualist profit? In which technologies for resource management? And will the recovered products be judged as no longer 'wastes', as customarily designated by hierarchical trading standards agencies, hence their return to society suppressed? Is an egalitarian ecological engineer an oxymoron (other than when used to describe the naturally evolved behaviour of a beaver)? For there was certainly much discussion of this when the journal *Ecological Engineering* was established in 1993 (witness McCutcheon et al., 1994). Is there – can there be – a fatalist school of engineering thought? Or is the significance of what attaches to the evolving understanding of the fatalists' outlooks confined to the idea of fatalisation? If so, is such fatalisation, of, say, hierarchical engineers, an important part of the seemingly insurmountable barrier (of risk-people-culture) to the innovation of cleantech into the water industry? For that was how one of us (MBB) would have summarised the predominant 'take-home message' from the discussion in a one-day seminar on the subject (Water and Cleantech) at the 2014 World Water Congress of the International Water Association (IWA).

At bottom, can there be a (fourfold, possibly fivefold) plurality of schools of engineering thought – a question we have started to ask ourselves, and started too to answer over the past two or three years (Beck, 2016; Thompson and Beck, 2017; Thompson et al., 2018; and Beck et al., 2018[3])? It is not that such a plurality would translate into a plurality of basic physics, chemistry, and biology (although such might be a possibility the more the knowledge base tends towards the somewhat divergent schools of thought behind the behaviour of ecosystems[4]). Rather, it is that the kinds of diverse technologies emerging from any plural schools of engineering thought will have to commend themselves, as it were, to the fourfold diversity of social solidarities, to the plurality of people's divergent and opposed beliefs about the way their worlds work. It has long been known that the very best available hierarchical technologies for reprocessing, storage, and disposal of nuclear wastes do not commend themselves in any shape or form to the egalitarian stakeholder – no matter the soundness of the science out of which they have developed.

We need an ethnography of water pollution control that reaches back into history to times well before that with which Verweij (2017) began his case study of the Rhine (the 1960s). Such a long sweep of history will serve to emphasise just how very early are these days (today) in the re-emergence of resource recovery in the water sector, roughly since the 1980s and 1990s. Counter-intuitively perhaps, despite a lot more history, we shall pivot away from illustrating plural rationality at work in water pollution control and waste management, as seen when looking backwards. Across Section 3, we turn to look the other way, to the future: to establishing a *prima facie* case for how our Viewpoint might instead help promote the introduction of not only resource recovery and management, but also the plural schools of engineering thought themselves. They will be the culmination of Section 3. Subsequently, in Section 4, we shall be concluding that something significant – along these probably surprising lines, of plural schools of engineering thought, that is – has already been evidenced in our work on applications of geotechnical and hydraulic engineering for landslide management in Italy (Linnerooth-Bayer et al., 2016; Scolobig et al., 2016).

[3] We note, however, that the shared plurality of thinking about risk in anthropology and engineering was first discussed well over a quarter of a century ago (Thompson, 1989).

[4] Ecological science has been held to comprise three schools of thought (Thompson, 1993): population dynamics (individualistic); climax community (hierarchy); and deep ecology (egalitarian). So contested were these schools, the advocates of each were fully capable of all but coming to blows with one another, as witnessed by one of us (MT) in a Workshop of the International Forum for Biophilosophy.

THE RE-EMERGENCE OF RESOURCE RECOVERY (FROM OUT OF THE DOMINANT SHADOW OF POLLUTION CONTROL)

If one looks far enough back, it is indeed the case that there *is* (almost) 'nothing new under the sun'. The concept of the sewage farm, now nearly entirely forgotten, hints at such. More explicitly, and looking much further back to the ancient origins of the egalitarian-like subject of ecological engineering, Mitsch et al. (1993) were able to express the following a quarter of a century ago:

> Ecological engineering is a concept which has been used informally in China for centuries and formally for the past 25 years.

We, however, will start this ethnography from just over two centuries ago.

A brief history

The 19th century

In 1796, Bridet acquired a patent in France for making *poudrette* (a fertiliser) from the urine and excrement in what is euphemistically called our 'night soil' (Barles, 2007a). More such innovations were to follow. During the 1850s and 1860s, patents for manufacturing related chemicals on an industrial scale came 'thick and fast' (Barles' phrasing). In the late 1700s, therefore, there were thriving (individualist) businesses for the recovery of fertiliser products in the city of Paris. The fertilisers were applied to the fields in the city's surrounding hinterland to grow the food that was then brought back into Paris, and so on and on, in quite a tight 'symbiotic' recycling loop. This (the 1790s through the 1850s) was for Paris "the age of no waste" according to Barles. In 1817, she records, 20% of the dietary N of Paris's (human) population was returned to agriculture.

Subsequently, with the introduction of household plumbing and later (from Britain) Thomas Crapper's arrangement of the water closet (WC), the quality and richness of the raw material for these enterprises – its nitrogen (N) and phosphorus (P) nutrient contents – was being diluted out by all the water. The result was the collapse of this profitable resource recovery industry by the 1920s.[5] The public good of securing public health in the city, but not the common-pool good of better quality for the waters of the Seine River (not that it would have been conceived of as such in those days), was being won at the expense of the lost private goods from the resource recovery businesses. Barles (2007a,b) does not report on whether this change of paradigm extinguished progress in the school of engineering thought underpinning the technologies and processes of nutrient recovery of the preceding century. But it seems highly likely it would have done so, as our synopsis of developments across the 20th century will shortly reveal.

History records too that most developed nations introduced urban water and sewerage services in the mid-1800s through (individualist) privately owned companies or private operators. It was not long, however, before these utilities were taken into municipal ownership, with the notable exception of those in France (Juuti and Katko, 2005). The municipal voice comes across with clarity in the (hierarchical-egalitarian) moniker 'social municipalism', even reinforced in the accusation – presumably from opposed private-sector actors – of this being 'water and gas socialism' (Barraqué et al., 2006).

The 20th century

In April, 1914, Ardern and Lockett presented a paper at a meeting of the Society of Chemical Industry (individualist sounding enough) on what they called the activated sludge process of wastewater

[5] At one stage, a peak return rate to agriculture of 40% of Paris's human dietary N was achieved (Barles, 2007a).

treatment (Ardern and Lockett, 1914). It was to become the signature technology of 20th-century municipal wastewater treatment and the core principle of the hierarchical school of engineering thought on the subject. Across the 20th century, gross pollution was deemed to be apparent in the aggregate measure of severely depleted levels of DO in rivers. Rectification of this poor state of affairs was the primary driver of the 'commanding and controlling' that was to be done. Pollution as measured in the 5-day BOD test – the gauge of the potential for river DO to be depleted in assimilating the easily degradable organic *carbon* (C) matter in municipal sewage and industrial wastes – was to be reduced as the urgent priority. The C in the waste was the focus; 'carbon-centric', one might say, was the prevailing thinking. Engineering design and operation of the activated sludge process were trained exclusively upon it. The scale of the technology and infrastructure expanded. As cities grew, and as the connection of households and industries to formal mains sewer networks became progressively more complete – through the technology of the WC – so the capacities of the attaching 'centralised' wastewater treatment plants grew. Such centralisation and large scale, we should note, are the favoured biases in the technological problem-solving procedures for those of a hierarchical persuasion. 'Big is best', as put in Figure 1. Resource recovery from the wastewater as such was displaced to the recovery (if anything) of C-based methane gas for the production of power, together with some soil-conditioning products. Yet little was made of these products as private goods. The methane was burned for on-site heat and light at the municipal wastewater treatment plant.

Across the second half of the century, thus to bracket the span of Verweij's case history of the Rhine, things became something of a matter of 'seek and ye shall find', as in finding other genres of pollution (in part, as noted earlier, as the blanket of the persistent C-centric pollution was being successfully lifted). A contemporary account of these developments – ones reflected in a distillate of the trends in computational modelling in support of water quality management (from roughly 1950 up to 1985) – is given in Beck (1985; Figure 1, p. 6). The continuing interest in restoring depressed DO levels had by that time grown to cover the oxygen-depleting capacity of easily degradable N-based pollutants; eutrophication in lakes had spurred a concentration of effort on removing P-based pollutants; other dimensions of N-based pollutants had been uncovered (nitrates in groundwater); and then, of course, there was the emerging problem of toxic substances, accompanied by the lengthening black lists to which they were being added (the 1986 Sandoz event on the Rhine was just a year away when this account was published). The N and P nutrient resources, so eagerly sought out in Paris's night soil, had come to be viewed as pollutants to be got rid of. A Specialist technical Group (SG) of the International Association on Water Pollution Research and Control (IAWPRC) – one of the predecessors of today's International Water Association (IWA) – was established to marshal and train professional engineering expertise onto making a comprehensive success of 'Nutrient *Removal*'.

To summarise, the closed hierarchical hegemony of command-and-control in managing water quality, and the (by now) paradigm of the hierarchical school of engineering thought supporting it, were utterly dominant. It was their heyday. There was substantial and deep lock-in: to the technologies of the WC, sewerage, and the centralised wastewater treatment plant. Ever more of the wastes were being gathered ever more into the focus of the point-source outlet to the environment. History, it might be concluded, was being forgotten, with the once 'knowns' (of nutrient recovery) sliding into the 'unknowns' – something redolent of the unknown knowns of a fatalised school of engineering thought. Few of us (MBB included) were questioning whether things could ever be otherwise.

The turn of the millennium

As the years passed, past the Brundtland Report on Sustainability of 1987, lone voices from within the approved school of engineering thought (for example, Niemcynowicz, 1993) were beginning to speak out against the utterly self-evident environmental good (surely!) of implementing the paradigm, and ever more efficiently. After the preceding quarter of a century of its formal use (and centuries of its informal use) the now newly insurgent, egalitarian-sounding concept of ecological engineering was securing the approved foothold of a journal – *Ecological Engineering* – in which to receive fuller recognition. The notion of the sustainable city, which had seemed such a contradiction in terms when first coined (*circa* 1988/9), if not a matter for dismissive scoffing, quickly became an accepted, legitimate, and familiar motivation.

But more than that, as the approach of the New Millennium came into sight, there was a growing, collective soul-searching, a questioning of something very basic: had man got his relationship with nature 'about right'? These became years in which nostrums and orthodoxies could be challenged, without one being branded a rebel or, worse, a crank (terms Funtowicz and Ravetz (1990) had used earlier in their book *Uncertainty and Quality in Science for Policy*).

What changed in respect of forms of governance for water pollution control? What changed about the way engineers could perceive and intervene in shaping man's interventions in nature?

The out-turn

Who indeed can recall now the prominence – as it was just a decade ago – of the Triple Bottom Line (Elkington, 1998)? Put very succinctly, it ran as follows (Beck, 2011; p. 18):

{Doing well now by the biosphere and the stock of natural capital
and flow of services therefrom entails doing at least as well generations hence}
Subject to attainment of this objective of 'doing well'
being witnessed by all the stakeholders to satisfy the properties of
{environmental benignity}
{economic feasibility}
&
{social legitimacy}

On {environmental benignity}, no longer would it suffice for the biochemical fate of wastes and pollutants on the aquatic environment to alone determine policy. Policy-technology interventions must also have regard for habitat, fish assemblages, species interactions, and ecosystems as wholes. The 'Savannah Process', so named for the river in the southeastern USA on which the prototypical process was developed, is indicative of the change (Richter et al., 2006; Arthington et al., 2006; Richter, 2010). The Process is notably a product of collaboration between the egalitarian-oriented Nature Conservancy and the hierarchical-leaning US Army Corps of Engineers.

On {economic feasibility}, another pairing of seemingly odd bedfellows may be used to highlight significant change. Beyond the 'natural capital', 'ecosystem services' (Liu et al., 2010), and 'service providers' of an individualistic business speak can be found 'value flows'. And their logic can be employed to grasp how exactly neoclassical economics, environmental economics, and deeply egalitarian variants of ecological economics may value the oysters in Chesapeake Bay, in particular, for their *own* sakes, not merely ours (Beck, 2016; Figure 13, p. 30).

Third and bottom-most (but surely not least), on {social legitimacy}, *governance* for all – hierarchical, individualist, egalitarian, and fatalist solidarities – has come to prevail over *government*, with its predominantly hierarchical command-and-control predisposition (Ney, 2009; Beck, 2011; Beck et al., 2011).

Foremost now in this Viewpoint is to enquire into what impacts these changes in outlook on our 'living with nature', which entails our 'getting along with one another', are having on engineering and technology in the built environment: for effecting the transition from waste to resource management. So this, as follows, is at the heart of what is to be put to the test in the coming years and decades. And if what we are setting out is genuinely a good idea, we have few illusions about its coming to pass in practice within the next 20 years.

Plural schools of engineering thought

The conceptual divide between man and nature comes down here to the focal point of effluents: those flows of water embodying what we deem we either do not need or cannot exploit for our own purposes, which are therefore released into nature. It is important to distinguish between facing inwards, peering into the man side of things – looking back, upstream from the effluent, into our socio-economic systems – and facing outwards towards nature and its natural ecological systems. We begin with the former.

Re-discovering the forgotten

As a point of departure into unpacking and revitalising the hierarchical school of the 20th century, let us focus on the conventional centralised wastewater treatment plant. Where formerly there was the IWA SG on Nutrient Removal for designing such plant, there is today the SG on Nutrient Removal *and Recovery*.[6] The Association has published a *State of the Art Compendium Report on Resource Recovery from Water* (Holmgren et al., 2015). In the Netherlands, there is a concerted effort to fashion 'Resource Factories' out of urban wastewater treatment plants, most notably that of Amsterdam (van der Hoek et al., 2016). Equally encouraging, and similarly directed towards the concept of 'Resource Recovery Facilities', is the review of Mayer et al. (2016).

To unwind further the historical convergence on centralising wastewater infrastructure, bring to mind the familiar counter-current of 'de-centralisation' and combine it with the phrase 'source separation'. A book on *Source Separation and Decentralisation for Wastewater Management* was published in 2013 (Larsen et al., 2013). It was the culmination of (yet another of those) two decades of questioning, first opened out in Larsen and Gujer (1996). But to appreciate the full import of the book, which resides in the 'source separation' phrase, consider this. The crude sewage delivered to the wastewater treatment plant is a highly dilute mixture of all manner of non-water resources. One of the richest sources of feedstocks, specifically for the production of N- (and P-)based fertilisers, is our urine. Until it was aired in an appropriate journal (*Water Science and Technology*), the notion of separating out urine from both faeces and the flush-water in the household WC must have seemed unthinkable. Once thought – and duly publicised and promoted – such source separation has exploded the conceptual framing of the 20th century paradigm of how wastewater infrastructure should be engineered.

Engineered and manufactured in the form of a urine-separating toilet (UST), to oust the oh-so-very familiar household toilet, and made somehow {socially legitimate} (Lienert, 2013),[7] source separation may become manifest in the historical, but otherwise centralised, wastewater infrastructure that has developed unceasingly since the stunningly successful introduction of Crapper's WC, into which the habits of many of us in the developed world have become deeply locked – into, as we know only too well, the water-based paradigm of sanitation.

Once upon a time there was dry sanitation. It gave rise to Bridet's patent of 1796 for the technology employed for resource recovery in Paris.[8] It too had slipped into the obscurity of an unknown known across the 20th century (and, shameful to recall, for far too many of we professional engineers). The UST has its *dry* counterpart, the Urine Diverting Dry Toilet (UDDT). Field trials have been conducted

---

[6] www.iwa-network.org/groups/nutrient-removal-and-recovery

[7] Such a pity, therefore, that Dake and Thompson's (1999) analysis of household consumption patterns using Cultural Theory could not have covered householders' views on the convenience of their UST, as opposed to their WC.

[8] Once too, there was a pneumatic (vacuum) technology system, i.e., a dry system, as opposed to the conventional (wet) sewer, for conveyance of the euphemistic night soil away from households in the Netherlands. Despite its feasibility having been demonstrated in Breda in 1867, its presence as such was short-lived (Geels, 2006: 1076).

with it, most notably in four out of the thirty administrative districts of the city of Ougadougou, Burkina Fasu (Dagerskog et al., 2010). If resource flows are not quite so finely separated (as *via* the UDDT), the toilet 'waste' of other forms of un-sewered sanitation can be fed into the time-honoured technology of composting – which is currently enjoying something of a renaissance (Drechsel and Hanjra, 2016; Hanjra et al., 2018). Such innovations and refinements of traditional practices signal renewed interest in emphasising the resource-cycling "nexus of sanitation and agriculture at municipal scale" (Drechsel and Erni, 2010). Put another way, it is a renewed interest in nutrient recycling around the urban, peri-urban, and rural landscapes (Hanjra et al., 2018). It is an instance of "Closing the Loop: Recycling Nutrients to Agriculture" (Jönsson and Vinnerås, 2013); it is the motivation to see "*Wastewater"*, in general, as an "*Economic Asset in an Urbanising World*" (Drechsel et al., 2015).

Indeed, where the wet paradigm is not already in place – where there *is* no drain down which to pour our money – the dry one may facilitate a kind of technological leap-frogging, sparked by a rewarding forgoing altogether of any putting-of-human-waste-into-the-water-cycle (Crutzen et al., 2007). As expressed elsewhere (in a pair of chapters for the Oxford University Press Handbook on *Food Water and Society*), it is not so much the water that is important, but what is in it (Thompson et al., 2018; Beck et al., 2018). Even if the wheel of history were not to be turned full cycle (and it never is), a journal of *Water Alternatives* might then prove to be a rather inappropriate forum for this present Viewpoint.

Burgeoning alternatives: Becoming 'more good', not just 'less bad'

There is yet something confining, albeit now no longer narrowing, about looking inward from effluent standards and back to the admonishing, but marvellously succinct, negative of the urban ecological footprint (Rees and Wackenagel, 1996). McDonough and Braungart (2002), for their part, in their landmark book *Remaking the Way We Make Things*, ask why it is we should be motivated only by the imperative of being 'less bad'. They urge upon us the complementary motivation of our being 'more good', with, we have to say, its unmistakable sense of opening out the way engineers may think about living with nature – the sheer *joie de vivre* of it (to break the taboo of suppressing anything even vaguely emotional about the subject of engineering – but see Florman, 1987). For McDonough and Braungart, 'waste' processing would not be merely a matter of downcycling ever more soiled goods, notwithstanding the fact that more astute downcycling would itself be an improvement on the *status quo*. For it would be a multiple, not single, use of the soiled goods before they are discarded. In our own water sector, for example, there is advocacy of water (of progressively higher degrees of impairment of its quality) being used for a variety and plurality of different purposes – water of plural qualities variously fit for plural purposes. 'Resource' processing, as we now urge (rather than waste processing), should also be a matter of upcycling, and preferably so. Imagine, as did McDonough and Braungart, designing a textile factory such that the factory's effluent water is of a higher quality than its influent water. That would be upcycling.

Thus can we slot in 'Man to be Less Bad' in Figure 1, in both quadrants of egalitarianism and hierarchy, and put 'Man to be More Good' in the corner of individualism.

One possible realisation of becoming and doing 'more good', to which we have devoted some considerable effort (see, for instance, Beck, 2011), is that of re-engineering the infrastructure of the city, in particular, its wastewater infrastructure, such that the city may become a 'force for good in the environment' (CFG, for short; see also the archive of documents at www.cfgnet.org).[9] Imagine not the 'bad' of the urban ecological footprint, but the 'good' of the city as a net generator of ecosystem

[9] Though it may exist, and perhaps already rightfully does exist, the companion AFG (Agriculture as a Force for Good in the environment) appears to generate primarily 'disservices', with the exception of contributing to curbing greenhouse gas emissions (Power, 2010). But this is to be predominantly less bad, not more good.

services. That is to face outwards to nature. And it is to raise our engineering thinking above and beyond compliance with effluent standards, even over-compliance (as achieved in the Rhine case history). It would be a school of engineering thought in some ways redolent of ecological engineering (but only in 'some' ways, as will become apparent!). For instance, the thrust of a 2016 IWA Outreach Paper (Applying Systems Thinking) is to argue that an improving grasp of the ('holistic') science underpinning what we observe and conceive of as ecosystem services in nature, is to nurture novelty in the body of ('reductionist') engineering knowledge to be put to work in rethinking and redesigning the city's resource-recovering and ecosystem-service-generating infrastructure (Beck, 2016).

More broadly – and to come to the crux of our Viewpoint – what we have said of plural rationality and clumsiness in governance and enterprise risk management in the human environment (in Section 2) is to hint, in effect, at an overarching framework for thinking about how technological innovation occurs, or does not, herein, in respect of the built environment. There are many (many) other such frameworks, for instance (to mention just a few) those advanced variously by, or discussed within, the papers of Geels (2005), Smith and Stirling (2010), Truffer et al. (2013), Kiparsky et al. (2013), Harris-Lovett et al. (2015), and Holmgren et al. (2015). More generally, there are the substantial works of Dosi et al. (1988) and Arthur (2011), with which latter, in particular, we have considerable sympathy, as will become evident in closing this Viewpoint in Section 4.

The following, then, are the stances of our plural schools of engineering thought. They will complete the instances of the theory of plurality in Figure 1; they are the culmination of our expression of the overarching framework in this Viewpoint.

Four archetypal schools

The Hierarchical School. Nature should be modified so that it holds a mirror up to an orderly society. When it gazes upon nature, an ordered society (which is how things should be) should see an ordered nature: 'Nature to Match Man' in Figure 1. A cordon – water and wastewater infrastructure – must be placed around man's socio-economic activities, especially in the case of the city (and likewise, CAFOs), to mitigate their substantial potential to pollute, hence defile, nature. Owners and operators of this infrastructure are to be policed to ensure their compliant behaviour: compliant, that is, with water supply standards for maintaining the security of citizens' public health and compliant with wastewater discharge standards for the protection of a vulnerable nature. There is a marked bias in this school towards complex, carefully planned, capital-intensive, centralised, and large-scale solutions (with economies of scale being emphasised and dis-economies being overlooked and parked in the background). 'Big is best', as we have said. The hierarchical school has something of a 'hands-on' approach to curbing man's excesses: the 'Hands-on Technocratic Control' of Figure 1.

The Egalitarian School. The mirror here works the other way: the affairs of society should reflect the marvellous 'workings' of nature, which are to be greatly revered; society should be changed to become more like nature. 'Man to Match Nature' in Figure 1. Nature should be brought ever more deeply and thoroughly into the heart of the city; its infrastructure should be green wherever possible, not the grey of concrete, steel, and so on. In one of its current guises this line of thought is referred to as 'nature-based' solutions to infrastructure design (European Commission, 2015). In mimicking the equally marvellously evolved workings of nature, the science called upon by engineers of the egalitarian persuasion emphasises the 'balance' among the plants and creatures that 'cohere' perfectly to form the 'wholeness' of ecosystems. Science of this kind is the opposite of reductionist; it concerns itself with the workings of the irreducible whole. 'Holistic Science' in Figure 1. Egalitarian engineers, unlike proponents of the other schools, urge that the hands of all engineers (their own included) be maximally removed from intervening in directing the affairs of their ecosystems (constructed wetlands, for example), once they are constructed and launched into operational action. Engineers of this persuasion shun the intensification and acceleration of the system's natural workings by the input of artificial chemicals and man-generated energy. The glory of these and other nature-based systems is that they are, like the naturally evolved ecosystem, *self*-organising and self-driven. In this school, with its accompanying entry in Figure 1, there is a 'hands-off' approach to encouraging the prosperity of nature. The abiding preference is for technology that is 'small and beautiful'.

The Individualist School. The hierarchical and egalitarian schools of thought both favour fettering the socio-economic activities of man. Both err on the side of our being less bad; both take the lead in hemming things in, albeit in their own distinctive, very different ways. In contrast, the individualist school of engineering thought has that certain *joie de vivre* about it: the pursuit of our being more good, hence its acquisition of the 'Man-to-be-More-Good' entry in Figure 1. It calls for de-regulation, the freedom to innovate and take risks, and for the internalisation of environmental costs so as to 'get the prices right'. It seeks to find that opening out of technological possibilities within the hemming-in of a hierarchical- or egalitarian-inspired policy framing. Exuberant trial-and-error, with the resulting technological solutions then being put into competition with one another, will ensure we quickly find our way along the best possible paths into the future. Individualistic engineers are agnostic in respect of which sciences (reductionist or otherwise; grey or green infrastructure) are mobilised in which way, at which scale, to facilitate that to which they are devoted as their priority: profitable resource recovery. The style of their technological preference has been caricatured as 'cheap and cheerful' (lower left quadrant, Figure 1). Like nutrient and carbon credit trading, policies and regulations for the hemming-in of man's economic activities should be phrased so as to liberate the *joie de vivre* of the individualist school.[11] Importantly, however, the 'hermit' within us should insist on the hemming-in being expressed from a clumsy, inelegant process of deliberation in governance.

The Fatalist School. Unsurprisingly, given what has been said above, a fully satisfying account of the fatalist school of engineering thought continues to elude us. There are 'blanks' for many of the entries they perhaps should have in their quadrant in Figure 1. Still, in addition to the advantages of recognising the presence and size of a fatalist solidarity (as listed in Section 2.2), what we can venture is this. The fatalised engineer, unlike those not so fatalised, each of whom learns in her or his distinctive way (according to the school(s) in which they were trained), has no capacity for learning. Innovation, therefore, can only happen by accident; but it is innovation nevertheless, so not to be sniffed at.

Closure

All in all, after a century or so of but one overwhelmingly dominant way of doing things (the hierarchical school of engineering thought), in which policy, infrastructure, and social habits have become inexorably bound ever more tightly together, it seems to us that we have passed through another quarter of a century of backing out of the pre-existing conceptual lock-in. But we have yet to back out of the deep physical lock-in of the technology and the associated material assets of the built environment. We might suppose that all of we professional engineers have thereby somehow been freed of the bindings of the 20th century paradigm. This is not the case; and on both the accounts of greatest concern to us, resource recovery, and plural rationality. For instance, as we write this paper (December, 2017), an engineering consultancy (which shall remain nameless) is offering training in "Phosphorus Removal and Tertiary Treatment Processes". The word 'removal' appears frequently in the course's programme; 'recovery' appears not at all. Just as disconcerting, the course lecturers look awfully young – too young (surely?) to have been steeped solely in the confining vat of the hierarchical paradigm of the 20th century!

---

[11] The US state of Pennsylvania, for example, operates its nutrient credit trading programme through the Pennsylvania Infrastructure Investment Authority (Pennvest; www.pennvest.pa.gov/Services/nutrient-credit- trading/Pages/default.aspx).

Elsewhere, on the second front, the engineering mindset can be observed to remain deeply entrenched and still very reluctant to let go of elegance (not just the fixation on nutrient removal), in particular, the elegance of the constrained optimisation of the quasi-mathematical program set out above in Section 3.1 for encapsulating what amounts to sustainability. We can find award-winning authors straining with every fibre of their thinking to expunge 'subjectivity' from their sustainability problem-solving procedure, only to admit to being forced back from attaining their goal of complete 'objectivity' (see the discussion in Beck, 2011, p. 18, citing Sharma et al., 2009). Clumsiness, from the outset, would never even entertain the prospect of such complete objectivity. But nor would it dismiss it as utterly irrelevant – far from it. It is quite at home in the quadrant of hierarchy in Figure 1, where it comes under the entry of 'Reductionist Science', *without* this phrase being intended in the pejorative sense. The engineers among us have read too many papers in which the 'quick engineering fix' is hurled dismissively at what has hitherto been presumed to be our camp (of reductionist science). Those papers have been authored by members of the opposing corner in the contentious (but impoverished) duopoly: of those holding to the 'Holistic Science' of the bottom-right camp in Figure 1.

To reiterate, it is *not* that this plurality of schools of engineering thought implies some corresponding plurality of knowledge bases for physics, chemistry, or biology, but that each school will need to commend itself, and its accompanying ways of mobilising its technological problem-solving skills, to each of the contending outlooks and preferences of stakeholders at the table of debate in governance. For there, with not a shred of doubt, there is (and should be) a plurality of outlooks on the way the world works. That notwithstanding, what has traditionally been known as environmental engineering (as a subdivision of civil engineering) is *the* branch of engineering most extended out into, hence deeply entangled with, the scientific uncertainties of all manner of the most exquisitely complex aquatic ecologies.

HOW DO ENGINEERS THINK?

Not surprisingly, it is *relatively* easy to find evidence of the time having come for the idea of switching from waste to resource management, and in pursuit of man being 'less bad': witness, for instance, the experiences from high-, middle-, and low-income countries alike reported in Larsen et al. (2013) and Drechsel et al. (2015). But that is not to suggest, by any stretch of the imagination, that this has become the norm. In respect of the broad absence of composting infrastructure at the scale of towns or cities, for example, this is said to be a failure resulting from the following (to quote Hanjra et al., 2018, p. 351):

> [an] over-reliance on technical solutions without sound market analysis, assessment of transport costs, business models, or strategies for collaboration with public sector services, municipalities, and farmers.

There is, however, evidence of what would once have been thought the unthinkable: of deliberately putting 'waste' phosphorus back into the natural environment – an instance of our seeking to become 'more good' in our interventions in nature – in order to arrest and reverse declining populations of salmon (Force, 2011; Pellett, 2010; as discussed in Beck, 2011).

We have practical evidence too of how the time has come for our other good idea: of the theory of plural rationality, as manifest in respect of "*Aid, Technology and Development*" in Nepal (Gyawali et al., 2017). That, however, was in circumstances where there was no drain to encourage the ever more deeply ingrained, locked-in habit of pouring money down it. These were not the circumstances in which our nascent, plural schools of engineering thought – the culmination of this Viewpoint – were needed for the task of unlocking resource management from within the closed (hierarchical) hegemony: of the long-sunk intellectual and economic investment in centralised sewerage and wastewater treatment. And for that it is very difficult (in fact, probably unrealistic) to find evidence of its time having come as yet.

Except that, as observed at the end of Section 2, we have good reason to believe there *is* a *prima facie* case for the existence of a plurality of schools of engineering thought, and the benefits to be derived therefrom. That case resides in the work of some of us (JL-B and MT) on landslide management in the Campania Region of Italy, specifically in a set of plural (three) portfolios of geotechnical and hydraulic-hydrological interventions, authored, notably, by members of the Faculty in the Department of Civil Engineering at the University Salerno (Linnerooth-Bayer et al., 2016). To that extent, we are encouraged to believe that the second element of our Viewpoint – building out the variety offered by the more deliberate cultivation of plural schools of engineering thought (as developed across Section 3) – is viable in practice.

Yet there is something more (and more subtle) about the landslide study. It does not actually address exactly what we are seeking. In contrast to the landslide analysis, our need for clumsiness is *not* so much for coping with contestation in highly charged disputes, but for generating breadth of scope and creativity in the possibilities for such interventions. Our need is largely that of confronting the issue of technical, technological, and engineering innovation in the face of lock-in. That would be the purpose in touching a plurality of technical-engineering bases in coming to the decision on what to do, instead of touching just *the one and only base*. To the building out of that, the more general introductory discussion of contested and uncontested 'terrains' of knowledge and problem-framing in Scolobig et al. (2016) is nevertheless highly pertinent.

Our experience of the one-day seminar on the subject of 'Water and Cleantech' innovation at the 2014 IWA World Water Congress was that of the 'insurmountable barrier' of people-risk-culture. Faculty of the Department of Environmental Social Science at EAWAG (Swiss Federal Institute of Aquatic Science and Technology) label it one of a deep-seated 'systemic innovation problem' (Truffer et al., 2013). Geels (2006), in his study of "The Hygienic Transition from Cesspools to Sewer Systems (1840-1930)", refers to the same in terms (of the almost war-like proportions!) of 'regime transformation'. All – barriers, systemic problems, entrenched regimes – add up to what engineer-economist Arthur refers to as lock-in (Arthur, 2011: 138-141). In short, he provides us with a most attractive way of understanding the nature of technological evolution and revolution, in our case, specifically, for what we are calling the built environment. But Arthur's book is silent on the role of the social anthropology of the human environment in technological change. It is likewise silent in respect of technological invention and innovation in that *specific* sub-domain of the engineered built environment central to this Viewpoint: mediating man's relationship with the natural aquatic environment. Indeed, we cannot resist this observation. There is some grand irony, and perhaps untold potential for resource management in the water sector, in the currently growing interest in attacking the *holistic* systems of microbial ecosystems in the human microbiome – that material which passes into humble toilet waste and compost – from the intensely *reductionist* stance of that most noble of contemporary sciences: molecular biology (Relman, 2012). We would wish to see this as a highly creative interplay between the hierarchical and egalitarian quadrants of Figure 1, along with those in the individualist quadrant duly pouring their cheap and cheerful *joie de vivre* into the mix.

In particular, we would like to cast this question – of innovation and breaking out of technological lock-in – as an important part of another, broader question. In a 1986 book, anthropologist Mary Douglas enquired into the nature of "How Institutions Think" (Douglas, 1986). Her book had to do, in part, with epistemologies (plural). Our Viewpoint has brought us to the point where we can no longer duck the increasingly urgent issue of asking, in much the same spirit: "How Do Engineers Think?".

REFERENCES

Aggarwal, A.; Beck, M. B.; Cann, M.; Ford, T.; Georgescu, D.; Morjaria, N.; Smith, A.; Taylor, Y.; Tsanakas, A.; Witts, L. and Ye, I. 2015. Model risk: Daring to open up the black box. *British Actuarial Journal* 21(2): 229-296.

Ardern, E. and Lockett, W.T. 1914. Experiments on the oxidation of sewage without the aid of filters. *Journal of the Society of Chemical Industry* 33(10): 523-539.

Arthington, A.H.; Bunn, S.E.; Poff, N.L. and Naiman, R.J. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. *Ecological Applications* 16(4): 1311-1318.

Arthur, W.B. 2011. *The nature of technology. What it is and how it evolves.* New York: Simon and Shuster.

Barles, S. 2007a. Urban metabolism and river systems: An historical perspective – Paris and the Seine, 1790-1970. *Hydrology and Earth System Sciences* 11: 1757-1769.

Barles, S. 2007b. Feeding the city: Food consumption and flow of nitrogen, Paris, 1801-1914. *Science of the Total Environment* 375: 48-58.

Barraqué, B.; Juuti, P.S. and Katko, T.S. 2006. Urban water conflicts in recent European history: Changing interactions between technology, environment and society. In *Urban water conflicts*, pp. 7-24. UNESCO Working Series SC-2006/WS/19, International Hydrological Programme (IHP). Paris: UNESCO.

Beck, M.B. 1981. Operational water quality management: Beyond planning and design. *Executive Report* ER-7. Laxenburg, Austria. International Institute for Applied Systems Analysis.

Beck, M.B. 1985. *Water quality management: A review of the development and application of mathematical models.* Berlin: Springer.

Beck, M.B. 2005. Vulnerability of water quality in intensively developing urban watersheds. *Environmental Modelling & Software* 20(4): 381-400.

Beck, M.B. 2011. *Cities as forces for good in the environment: Sustainability in the water sector.* Athens, Georgia: Warnell School of Forestry and Natural Resources, University of Georgia. http://cfgnet.org/archives/587

Beck, M.B. 2016. Understanding the science of ecosystem services: Engineering infrastructure for urban water services. *Applying systems thinking: An outreach paper.* The Hague, The Netherlands: International Water Association. www.iwa-network.org/ecosystem-services-not-so-much-the-water-as-what's-in-it/

Beck, M.B.; Jiang, F.; Shi, F.; Villarroel Walker, R.; Osidele, O.; Lin, Z.; Demir, I. and Hall, J.W. 2010. Re-engineering cities as forces for good in the environment. *Proceedings of the Institution of Civil Engineers*, *Engineering Sustainability* 163(ES1): 31-46.

Beck, M.B.; Thompson, M.; Ney, S.; Gyawali, D. and Jeffrey, P. 2011. On governance for re-engineering city infrastructure. *Proceedings of the Institution of Civil Engineers*, *Engineering Sustainability* 164(ES2): 129-142.

Beck, M.B.; Gyawali, D. and Thompson, M. 2018. Societal drivers of food and water systems, Part II. In Bromwich, B.; Allan, A.; Coleman, A. and Keulertz, M. (Eds), *Handbook on food water and society*, Oxford University Press, Oxford, (in press).

Crutzen, P.J.; Beck, M.B, and Thompson, M. 2007. "Cities". Blue Ribbon Panel on Grand Challenges for Engineering, US National Academy of Engineering (see also *Options* (Winter, 2007), Laxenburg, Austria: International Institute for Applied Systems Analysis, p. 8). www.engineeringchallenges.org

Dagerskog, L; Coulibaly, C. and Ouandaoga, I. 2010. The emerging market of treated human excreta in Ouagadougou. *Urban Agriculture Magazine* 23: 45-48. www.ruaf.org

Dake, K. and Thompson, M. 1999. Making ends meet: In the household and on the planet. *GeoJournal* 47: 417-424.

Dosi, G.; Freeman, C.; Nelson, R.; Silverberg, N. and Soete, L. (Eds). 1988. *Technical change and economic theory.* London: Pinter.

Douglas, M. 1966. *Purity and danger: An analysis of concepts of pollution.* London: Routledge.

Douglas, M. 1986. *How institutions think.* Syracuse, New York: Syracuse University Press.

Drechsel, P. and Erni, M. 2010. Analysing the nexus of sanitation and agriculture at municipal scale. *Urban Agriculture Magazine* 23: 11-12. www.ruaf.org

Drechsel, P. and Hanjra, M.A. 2016. Green opportunities for urban sanitation challenges through energy, water, and nutrient recovery. In Dodds, F. and Bartram, J. (Eds), *The water, food, energy and climate nexus: Challenges and an agenda for action*, pp. 204-218. London: Earthscan from Routledge.

Drechsel, P.; Qadir, M. and Wichelns, D. (Eds). 2015. *Wastewater. Economic asset in an urbanizing world.* Springer, Berlin.

Elkington, J. 1998. *Cannibals with forks: The triple bottom line of 21st century business.* Stony Creek, Connecticut: New Society.

European Commission. 2015. Nature based solutions & re-naturing cities. *Final Report*, Brussels: Horizon 2020 Expert Group, Directorate General for Research and Innovation, European Commission.

Florman, S. 1987. *The existential pleasures of engineering.* New York: Macmillan.

Force, J. 2011. The ultimate recycling. *Treatment Plant Operator*, pp. 12-17.

Funtowicz, S.O. and Ravetz, J.R. 1990. *Uncertainty and quality in science for policy.* Dordrecht, The Netherlands: Kluwer.

Geels, F. 2005. Co-evolution of technology and society: The transition in water supply and personal hygiene in the Netherlands (1850-1930) – A case study in multi-level perspective. *Technology in Society* 27(3): 363-397.

Geels, F. 2006. The hygienic transition from cesspools to sewer systems (1840-1930): The dynamics of regime transformation. *Research Policy* 35(7): 1069-1082.

Gyawali, D.; Thompson, M. and Verweij, M. (Eds). 2017. *Aid, technology and development.* London: Earthscan from Routledge.

Haigh, N. 1984. *EEC environmental policy and Britain.* London: Environmental Data Services.

Hanjra, M.A.; Lydecker, M.; Drechsel, P. and Paul, J. 2018. Rural-urban food and nutrient dynamics and nutrient recovery from waste in developing countries. In Zeunert, J. and Waterman, T. (Eds), *Routledge handbook of landscape and food*, pp. 344-365. New York: Routledge.

Harris-Lovett, S.R.; Binz, C.; Sedlack, D.L.; Kiparsky, M. and Truffer, B. 2015. Beyond user acceptance: A legitimacy framework for potable water reuse in California. *Environmental Science and Technology* 49: 7552-7561.

Holling, C.S. 1977. Myths of ecology and energy. In Kiefer, I. (Ed), Proceedings of the Conference on "*Future Strategies for Energy Development"* (21-22 October, 1976), pp. 34-39. Oak Ridge, Tennessee: Oak Ridge Associated Universities.

Holling, C.S. (Ed). 1978. *Adaptive environmental assessment and management.* Chichester: Wiley.

Holmgren, K.E.; Li, H; Verstraete, W. and Cornel, P. 2015. *State of the art compendium report on resource recovery from water.* The Hague, The Netherlands: International Water Association.

Ingram, D. and Thompson, M. 2011. Changing seasons of risk attitudes. *The Actuary* (US) 8(1): 20-24.

Jönsson, H. and Vinnerås, B. 2013. Closing the loop: Recycling nutrients to agriculture. In Larsen, T.A.; Udert, K.M. and Lienert, J. (Eds), *Source separation and decentralization for wastewater management*, pp. 163-178. London: IWA Publishing.

Juuti, P. and Katko, T. (Eds). 2005. *Water, time, and European cities: History matters for the futures*. Tampere, Finland: Tampere University Press.

Kiparsky, M.; Sedlack, D.L.; Thompson, B.H. and Truffer, B. 2013. The innovation deficit in urban water: The need for an integrated perspective on institutions, organizations, and technology. *Environmental Engineering Science* 30(8): 395-408.

Larsen, T.A. and Gujer, W. 1996. Separate management of anthropogenic nutrient solutions. *Water Science and Technology* 34(3-5): 87-94.

Larsen, T.A.; Udert, K.M. and Lienert, J. (Eds). 2013. *Source separation and decentralization for wastewater management.* London: IWA Publishing.

Lienert, J. 2013. High acceptance of source-separating technologies – But... In Larsen, T.A.; Udert, K.M. and Lienert, J. (Eds), *Source separation and decentralization for wastewater management,* pp. 193-207. London: IWA Publishing.

Linnerooth-Bayer, J.; Scolobig, A.; Ferlisi, S.; Cascini, L. and Thompson, M. 2016. Expert engagement in participatory processes: Translating stakeholder discourses into policy options. *Natural Hazards* 81(S1): S69-S88.

Liu, S.; Costanza, R.; Farber, S. and Troy, A. 2010. Valuing ecosystem services. theory, practice, and the need for a transdisciplinary synthesis. *Annals of the New York Academy of Sciences* 1185: 54-78.

Mayer, B.K.; Baker, L.A.; Boyer, T.H.; Drechsel, P.; Gifford M.; Hanjra, M.A.; Parameswaran, P.; Stoltzfus, J.; Westerhoff, P. and Rittman, B.E. 2016. Total value of phosphorus recovery. *Environmental Science & Technology* 50: 6606-6620.

McCutcheon, S.C.; Mitsch, W.J.; Walski, T.M.; Odum, H.T. and Odum, E.P. 1994. Joint Editorials. *Ecological Engineering* 3: 107-109.

McDonough, W. and Braungart, M. 2002. *Cradle to cradle: Remaking the way we make things*". New York: North Point Press.

Mitsch, W.J.; Yan, J. and Cronk, J.K. 1993. Ecological engineering – Contrasting experiences in China with the West. *Ecological Engineering* 2(3): 177-191.

Ney, S. 2009. *Resolving messy policy problems: Handling conflict in environmental, transport, health and ageing policy.* London: Earthscan.

Niemczynowicz, J. 1993. New aspects of sewerage and water technology. *Ambio* 22(7): 449-455.

Pellett, K. 2010. *Salmon river watershed enrichment for fish habitat restoration. Report* (Project # 09.CBR.03). Nanaimo, British Columbia, British Columbia Conservation Foundation (March).

Power, A.G. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society B* 365: 2959-2971.

Rees, W.E. and Wackernagel, M. 1996. Urban ecological footprints: why cities cannot be sustainable – and why they are key to sustainability. *Environmental Impact Assessment and Review* 16: 223-248.

Relman, D.A. 2012. The human microbiome: Ecosystem resilience and health. *Nutritional Review* 70(Suppl 1): S2-S9.

Richter, B.D. 2010. Re-thinking environmental flows: From allocations and reserves to sustainability boundaries. *River Research & Applications* 26: 1052-1063.

Richter, B.D.; Warner, A.T.; Meyer, J.L. and Lutz, K. 2006. A collaborative and adaptive process for developing environmental flow recommendations. *River Research and Applications* 22: 297-318.

Scolobig, A.; Thompson, M. and Linnerooth-Bayer, J. 2016. Compromise not consensus: Designing a participatory process for landslide risk mitigation. *Natural Hazards* 81(S1): S45-S68.

Sharma, A.K.; Grant, A.L.; Grant, T.; Pamminger, F. and Opray, L. 2009. Environmental and economic assessment of urban water services for a greenfield development. *Environmental Engineering Science* 26(5): 921-934.

Smith, A. and Stirling, A. 2010. The politics of socio-ecological resilience and sustainable socio-technical transitions. *Ecology & Society* 15(1): 11, www.ecologyandsociety.org/vol15/iss1/art11.

Thompson, M. 1979. *Rubbish theory: The creation and destruction of value.* Oxford: Oxford University Press.

Thompson, M. 1989. Postscript: Engineering and anthropology: Is there a difference? In Brown, J. (Ed), *Environmental threats: Perception, analysis and management*, pp. 138-150. London: Belhaven.

Thompson, M. 1993. Good science for public policy. *Journal of International Development* 5(6): 669-679.

Thompson, M. 2002. Man and nature as a single but complex system. In Timmerman, P. (Ed) *Encyclopedia of Global Environmental Change*, pp. 384-393. Chichester: Wiley.

Thompson, M. 2008. *Organising and disorganising: A dynamic and non-linear theory of institutional emergence and its implications.* Axminster: Triarchy.

Thompson, M. 2017. *Rubbish theory: The creation and destruction of value* (Second and extended edition). London: Pluto.

Thompson, M. and Beck, M. B. 2017. Afterword. In *Rubbish theory: The creation and destruction of value* (Second and extended edition), 229-252. London: Pluto.

Thompson, M. Ellis, R. and Wildavsky, A. 1990. *Cultural theory.* Boulder, Colorado: West View.

Thompson, M.; Beck, M.B. and Gyawali, D. 2018. Societal drivers of food and water systems, Part I. In Bromwich, B.; Allan, A.; Coleman, A. and Keulertz, M. (Eds), *Handbook on food water and society*, Oxford University Press, Oxford, (in press).

Trucost. 2013. *Natural capital at risk: The top 100 externalities to business.* London: Trucost.

Truffer, B.; Binz, C.; Gebauer, H. and Störmer, E. 2013. Market success of on-site treatment: A systemic innovation problem. In Larsen, T.A.; Udert, K.M. and Lienert, J. (Eds), *Source separation and decentralization for wastewater management,* pp. 209-223. London: IWA Publishing.

Tsanakas, A.; Beck, M.B.; Ford, T.; Thompson, M. and Ye, I. 2014. Split personalities. The IFoA's model risk working party reflects on the cultural aspects of risk. *The Actuary* (December 2014): 34-35.

van der Hoek, J.P.; de Fooij, H. and Struker, A. 2016. Wastewater as a resource: Strategies to recover resources from Amsterdam's wastewater. *Resources, Conservation and Recycling* 113: 53-64.

Verweij, M. 2000. *Transboundary environmental problems and cultural theory: The protection of the Rhine and Great Lakes.* Basingstoke: Palgrave Macmillan.

Verweij, M. 2011. *Clumsy solutions for a wicked world: How to improve global governance*. Basingstoke: Palgrave Macmillan.

Verweij, M. 2017. The remarkable restoration of the Rhine: Plural rationalities in regional politics. *Water International* 42(2): 207-221.

Verweij, M. and Thompson, M. (Eds). 2006. *Clumsy solutions for a complex world: Governance, politics and plural perceptions.* Basingstoke: Palgrave Macmillan.

Villarroel Walker, R.V. and Beck, M.B. 2014. Nutrient recovery. Nexus innovation impact analysis. *Insight* 1, BeCleantech Initiative, Sustainability Specialist Group, International Water Association, www.becleantech.org, see also http://cfgnet.org/archives/1528

Zeitoun, M.; Lankford, B.; Krueger, T.; Forsyth, T.; Carter, R.; Hoekstra, A.Y.; Taylor, R.; Varis, O.; Cleaver, F.; Boelens, R.; Swatuk, L.; Tickner, D.; Scott, C.A.; Mirumachi, N. and Matthews, N. 2016. Reductionist and integrative research approaches to complex water security policy challenges. *Global Environmental Change* 39: 143-154.