Using an information processing architecture as an aid to optimising technology choice for faecal wastes and domestic waste water: Part I – Encapsulating Nature

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1 Introduction

In a 1983 book titled "Sanitation and disease: health aspects of excreta and wastewater management" published by the World Bank the authors reviewed the history of sewerage and concluded that: "*These practices are not especially clever, nor logical, nor completely effective – and it is not necessarily what would be done today if these same countries had the chance to start again*". Today sewerage treatment stations are more complex so they are a little more effective, but not much else has changed. Indeed, Steve Couper a past president of Water New Zealand notes as recently as July 2013 that "*Surely a shift in thinking from energy hungry wastewater plants to one of opportunity for resource recovery needs to be the future focus of our sector, along with looking at the whole environment....*" (*Water*; July 2013, P.2). The fact that there has been little change in the industry in the 30 years between these two observations points to structural issues that stifle critique of the current system. It follows that a methodology that steps outside the industry and can critique its internal functioning is needed.

As a contribution to this, it is argued here that Nature[1] can be encapsulated within an *information processing structure* (Structure). As the behavioural characteristics of the underlying laws and processes pre-existed humans, then any use of this Structure is also outside all human constructs, and this includes the industry and all known technologies. It follows that using such a Structure means that we can approach any optimisation question without pre-conceived notions arising from the human domain.

An information processing *architecture* takes this Nature-based *Structure* and adds to it: considerations of its lower and upper boundaries; and the manner of human interaction with it. The lower boundary is argued to be best located at the 'chemistry conjunction'; this being where physics meets biology and all analysis systems are linked – particularly useful in the waste water industry are mass balance and thermodynamics. The upper mathematical boundary of Nature's Structure is argued to be best located in the mathematics on the **Nature** side of the Nature/human interface, thereby giving Nature a clear voice. In contrast, the physical boundaries of the architecture need to be located

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[1] Nature in this context includes the behaviour and organisation of all life forms using carbon as an energy source that existed before humans developed complex societies and science. In this context, the fundamental laws and processes are a mathematical description of what humans observe in Nature's behaviour. Nature's behaviour has not changed due to the development of this method of description. However, in being a human construction, mathematics provides a very useful mechanism by which the behaviour of Nature can be incorporated into human decisions as it can, on the one hand, describe Nature's behaviour while on the other hand, can be used by engineers to develop technologies.

to include human environmental impacts (read receiving waters). A second physical boundary based on a technology is useful if the *system* contains several technologies operating in series and/or parallel.

Sustainability considerations attach very easily to Nature's mathematical Structure. This is possible because the zeros that are implicit in sustainable use of resources are synonymous with the mathematical procedure of minimisation. Consequently, sustainability can express as an initial narrowing of the focus of a Structure, and become visible as a 'Beacon' against which each technology can be measured as to the degree to which it meets this perfection. Sustainability questions therefore reduce to consideration of the location of the boundaries of the architecture and the manner of human interaction with it.

This paper details the architecture and its boundaries while Part II of this series looks at human complexity (Chapman, 2014a). The linkages between the two (considered to be tools that aid the optimisation process) are discussed in Chapman (2014c).

2 What constitutes an optimum?

In the waste water industry, the need for some notion of an optimum arises because a range of methods (particularly technologies) have been developed for influencing the conditions within which Nature operates. Different methods have different outcomes, meaning a choice must be made between competing technologies. If different methods have different outcomes then it is possible to first define the desired outcomes and then choose the best methods to meet the desired outcomes. Raising the question as to what is to be optimised?

While it is easier to optimise for a single parameter, this can lead to a sequence of decisions separated over time with possible sub-optimal outcomes arising from those components that were not part of the original decision. The history of sewerage systems is full of examples of these sub-optimal outcomes from using such an approach (Benidickson, 2007). We need to be able to question whether any particular technology is the best it can possibly be.

However, if we begin the analysis with all the complexity in the context, then this beginning stance includes these potentially adverse consequences. Given that all possibilities are in the starting assumptions then the optimum will be the set of technologies that best meets **all** of the requirements within the limits of the environmental conditions and resources of the community, and current state of knowledge and technology development of the world.

This is an exercise in managing multi-component optimisation.

At first glance, the overwhelming complexity would appear to exclude any notion of consideration of an optimum technology. However a processing framework (architecture) that ensures all the necessary components are involved can be formulated for this purpose. In particular, Nature's voice needs to be heard through the cacophony of social processes and this voice needs a mechanism by which it can be given due consideration.

In essence, all the complexity of Nature can be 'packaged' into a mathematical structure which acts as a single entity in the optimisation procedure. As a result, the complexity of social systems can be more focussed, enabling optimisation questions to move from the technology details to the boundary between the two major systems – Nature and society.

3 Information processing architecture

An information processing architecture uses the computational power that derives from three elements that comprise the architecture: its internal organisation that is embodied in at least one *information processing structure* (Structure); the location of its boundaries; and the manner of human interaction with it.

If all of the information needs to be present, else the missing information may prevent identification of the optimum, then the architecture needs to have characteristics that enable it to embrace the vast complexity of Nature, yet interface with the complexity of human social systems and our technologies. The common thread providing this linkage is information, for which each component that participates in the architecture needs the relevant information to be in a form that can participate in the process.

3.1 Building information processing structures

Information processing structures are an essential part of the overall architecture. Their primary task is to encapsulate Nature (or more particularly, the mathematical descriptions of Nature). Nature existed long before she was used in human technologies, or science developed ways of describing the observed behaviour; indeed, it was observations of Nature's behaviour that led to the derivation of the fundamental laws and processes. As the behaviour pre-existed humans, then using these 'descriptions of Nature' chooses a part of the complexity that is free from all human influences.

It is particularly useful that these descriptions use the discipline of mathematics as on the one hand are the forms that describe this pre-human behaviour of Nature, which then **carry** this information into subsequent use of the mathematical form. These information-rich mathematical symbols can be manipulated by any of the mathematical tools that are available, yet the symbol retains their underlying information.

On the other hand, are the socially useful disciplines that use the same mathematics (such as engineering) and their role in organising any complex society. Linking the two therefore enables Nature to express in human technology development. For which we need to develop mechanisms by which social processes can access this mathematics – a number of methods are discussed in the various papers that form part of this series for which interested readers would be best to start with Chapman (2015c).

The mathematics describing Nature's processes is inherently shapeless and boundless. Consequently, when Chapman used diffusion laws in composting to describe oxygen concentration then it was necessary to begin with the concentration in free-air (and thereby include all those influences that affected the concentration at the microbe's particular location). However, this characteristic of the fundamental laws and processes is very useful as it allows external influences to access the very core of the Structure; such as the temperature effect acting on several constants and coefficients in composting. Indeed, **every** parameter in the mathematics of the Structure requires all influences that impact on its state at any point in space or time to fully express.

To ensure that all of the complexity of Nature can be linked to the complexity of social systems, a necessary condition is that each component of Nature's complexity can demonstrate that it can influence the output. The notion of seamlessness, as a vehicle for carrying the underlying causation that is being described by the underlying fundamental laws and processes into the Structure, is a formalisation of this need (Chapman, 2010c).

For any particular technology, there are three ways of enabling this:

- First, by using the mathematical entity that describes the component's behaviour – diffusion laws and microbial kinetics in the case of Chapman (2008).
- Second, it can influence (or be) a parameter in the mathematics encased within the boundaries. Particular care is required to ensure that *external* influences can express. For example, the temperature effect in composting needs a finite volume method to create modelling space by which the value of several constants/coefficients can change in response to temperature (Chapman, 2010b).
- Third, by consideration of the location of the boundaries of the structure that enables consequences to be involved.

Both the internal organisation and the outer boundaries are important. The first two of the above points are discussed in depth in other papers while the third, the location of the boundaries, has most value when Structures are used in the social context and are particularly relevant to the optimisation question being raised here.

3.2 The architecture boundaries

In a technology, Nature is acting within certain physical boundaries, such as the physical limits of a composting pile which need to the known in order to determine the oxygen concentration surrounding each particle. However, using a mathematical description within a physically bounded technology means that there are two types of boundaries to consider: the mathematical boundaries that are mostly involved in describing Nature, and the physical boundaries that are implicit in our technologies and the environmental consequences of these technologies. The two boundaries are separate but interconnected. Only the mathematical parameters whose value is affected by the physical boundary (such as pile-air oxygen concentration in composting) need to consider the consequences of this interconnection.

3.2.1 The lower mathematical boundary

For a system that utilises Nature, it is microbial kinetics acting on organic matter and the need for all influences to express that leads to the chemistry conjunction, as both substrate and electron acceptor are chemical compounds that are critical in determining the value of the rate constant. The chemistry conjunction is very useful as a lower mathematical boundary as this is the point where physics meets biology and all analysis systems are linked. Mass balance laws, thermodynamics, microbial kinetics etc meet at the chemistry conjunction. Using this as a starting point for the Structure means all possible analysis paths are implicit.

The use of bottom-up modelling from the chemistry conjunction is advocated (Chapman, 2010a). This builds a Structure that enables expression of all the fundamental laws and processes and cuts out detail that has little relevance to the larger decision. Such formulations have been shown to be possible in composting (Chapman, 2008) where it generates a spatial complexity which is embedded in the onion-ring type volumes of compost that accurately describes the real-world behaviour, as reflected in the high regression coefficient with experimental data ($r^2 > 0.99$) (Chapman, 2009).

The chemistry conjunction is also a very good basis from which to begin bottom-up modelling for the social context as any analysis requires a set of starting conditions for the material under consideration; that is the quantity (and state) of faeces, urine and greywater. It follows that if the analysis begins with the material before entering any technology, then a linkage is established between Nature (or more particularly, the mathematical descriptions of Nature) and humans that **precedes** any technology and therefore contains no bias and is independent of current technologies and the institutional frameworks that surround these technologies. It also implicitly includes all technological possibilities – even those not yet discovered. In the case of sewerage, the same analysis framework can apply to each of the components separately or when mixed. So it is possible to compare separate treatment of each component with treatment of all combined.

3.2.2 The upper mathematical boundary

Bottom-up modelling begins at the chemistry conjunction, but has no inherent limit for its upper boundary. The point to stop building in more complexity is undefined; yet an information processing architecture contains an inherent notion of a limit. There is therefore a need to consider an upper boundary to the Structure. It is suggested that this upper boundary be located *in* the mathematics on the Nature side of the Nature/human interface. This location then encapsulates only Nature in the Structure without distortion from existing technologies, albeit the formulation may be specific to a particular type of technology. But more importantly, this location generates a **creative boundary** between Nature and human use of Nature in the technology. By making this separation, an Information Processing Structure **becomes** Nature in a mathematical form and it is the mathematics that provides a linkage between the behaviour of Nature and human understanding (and use) of this behaviour in the particular technology.

In effect the location of the upper mathematical boundary is an arbitrary division within the complexity, there being considerable complexity on both sides of the boundary. However, choosing the boundary location based on its functional usefulness (that is, separation of Nature from the technology that utilises Nature) means that the same Structure can then apply to all forms (and operating procedures) of the particular technology. It becomes an ‘information-rich package’ that will give a different answer for each application and is particularly useful for the optimisation questions being asked here.

By way of example of the creativity inherent in this boundary, the Beacon emerges when the upper mathematical boundary is set **pre-technology** and the sustainability zeros are used in the minimisation procedure (discussed further below).

3.2.3 The physical boundaries

For a system which can be composed of several different technologies it is convenient to separate the physical boundaries into two:

- Technology boundary
- System boundary

Within the technology boundary the use of a separate Structure for each set of different variables may be advantageous to consider. In this case, several Structures could exist within a single technology boundary (such as the separation of anoxic zones from the aerobic zones within an AWS system). Interconnections exist between the Structures in this case – such as the anoxic/anaerobic proportion being 1 minus the aerobic proportion in Chapman’s formulation, but each can be analysed separately within limits set by the interconnections. Indeed, the technology boundary need not even be a technology in the physical sense; such as the treatment that occurs within the soil layer of a land disposal method for effluent, which could be analysed as if they were a separate technology.

In contrast, the *system* boundary is particularly useful as it provides a way of incorporating adverse environmental effects into the analysis. The physical boundary of the system under consideration does not need to be confined to a particular technology’s physical boundaries. Many environmental issues arise because adverse consequences are (or have been) external to decisions. These adverse consequences can be accommodated in the architecture by consideration of the physical boundaries of the system. The carbon, water and nutrient cycles will be completed through Nature; humans can only influence some of the paths that these cycles utilise. For example, it was only learnt from experience that using rivers to complete the cycles for sewerage was sub-optimal. It follows, that if rivers are included in the analysis (in effect drawing the boundary at the river/ocean junction) and we don't like the consequences, then their contribution to completing the cycles needs to be zero – alternatively simplify the analysis by locating the physical boundary before any discharge enters the river and set the need for further treatment to 0.

Drawing the boundary around the environmental impacts includes them in the architecture. Being in the architecture they influence the output. In effect, the system can be composed of many technologies that exist in series or parallel, but all will exist within the system boundary. For example, including sludge disposal within the system's boundaries means that any technology which does not generate sludge will be able to be compared with competing technologies on an equal footing.

It is the physical boundaries, and the degree to which the great cycles of Nature complete within these physical boundaries, which carry much of the information of the human requirements into the architecture; this makes it useful.

Including these impacts within the system being analysed has two consequences: first, a technology that achieves the best environmental outcome (as measured by its ability to complete the great cycles with minimum adverse environmental consequences) can be identified independently of the incumbent technologies and second, it can be a socio-economic decision as to whether to pursue this technology option.

Optimisation includes many elements that touch on all aspects of the human/planet interface, little wonder we avoid attempts at the best decision.

3.3 Using the zeros as a Beacon – sustainability as a mathematical procedure acting on Nature's Structure

Within this theoretical framework, a major component of the sustainability question; the zeros of the social sphere: zero pathogens, zero nutrient discharge, zero water use and zero energy use, can be addressed by the mathematical requirement for minimisation. In this role, the Structure's output when minimised can act as a direction indicator rather than an absolute target for humans – clearly reuse of nutrients for food production is preferable to discharge to a water course.

For any particular faeces immediately after defecation, the presence of micro-organisms (which are everywhere) and sufficient moisture for microbial degradation to occur, means that this is sufficient for microbial kinetics and diffusion laws, acting over time, to complete the carbon and nitrogen cycles without needing any form of technology, receiving waters or soil (the liquid could be evaporated). Albeit, the organic matter's physical presence will require a location and a surface to rest upon and the non-volatile macro-nutrients will remain – but the immediately preceding scenario is a hypothetical argument. An information processing structure that adequately describes this process and uses bottom-up modelling to build this Structure begins, in this case, with all the zeros being fully met and this includes the possible existence of technologies that meet all the zeros.

This, possibly unattainable technology, can exist as a Beacon, a direction indicator against which the proximity to the Beacon can be considered a measure of the value of any particular technology in meeting this perfection. If the currently available technologies are not suitable then it is desirable that both: scrutiny of their adequacy and movement towards more desirable technologies occurs. This creates a boundary, a ‘tension’, between where we are and where we could be. This is one way of arranging the information arising from the architecture into a form that can be used by society and has links to the long-term dynamic of human societies (or more particularly, preventing the problems that arise from not responding to emerging issues).

There is therefore no impediment to beginning the analysis with all the zero conditions being fully met. The compromises are not a constraint of the beginning assumptions; rather they occur later in the path. Locating the compromises in this position in the analysis means that each proposed solution to a compromise can be scrutinised as to its adequacy, which is a position likely to be beneficial to development of more appropriate technologies in the future. The focus is centred on the need for the compromise as well as the mechanism to transcend it.

Other attributes of the Beacon are discussed in Chapman (2015d).

4 Conclusion

Beginning the analysis from the chemistry conjunction, as it applies to each of the waste streams after they leave the body (in the case of faeces and urine) but before they enter a technology means that each of the streams will have a set of physical characteristics: volume, particle size, moisture content; and an associated set of other characteristics of relevance such as: pathogens, organic fractions, mechanical strength etc. The point just before each waste stream enters a technology therefore identifies a good starting point to allow determination of an optimum technology combination, as both the chemistry conjunction and the social requirements can be fully expressed. Questions such as “is it possible to destroy the pathogens without using energy and enable reuse of nutrients with a technology that is resilient to natural disasters?” can be asked. All the possible ways of destroying pathogens are implicit in the question: chemical, UV, filtration, and the biological suite of effects manifesting in the time/temperature die-off curve, as are all possible technologies.

Rather than abstract a part of the full complexity at the beginning to make the problem ‘manageable’, this approach embraces the full complexity and allocates it to two domains: Nature and human use of Nature. Each domain is tasked with managing the interconnections that occur within its bounds. The boundary between the two domains can then be formulated in many different ways to provide the necessary insights. Indeed the complexity could be considered to be in layers where the question of the optimum technology/method sits between the two great areas of complexity: Nature and human social systems. The complexity of Nature is embedded in the mathematics of the Structure, while the complexity of humans is embedded in the manner of our interaction with Nature’s Structure, and our response to the information. The relevant information is processed and presented by the architecture, at the same point in the complexity that humans develop technologies to solve various issues.

The mathematical Structures that form within the overall architecture are very information dense, so extracting the most useful information is an issue of considerable significance and is discussed further in Part II (human complexity (Chapman, 2014a)) and the interconnections between the two in (Chapman, 2014c).

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