Opening information feedback loops as an aid to good decision making in a complex world: a sewerage case study

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1. Introduction

In a recent debate on a proposed community sewerage scheme for Glenorchy, highly relevant evidence indicating that consideration of a different set of technologies would better meet sustainability criteria was studiously ignored. Ignoring the evidence prevented the community from attempting to grasp the potential that lay before it. This raised the question: why was the evidence ignored?

Systems thinking asserts that for complex systems, information feedback loops fill an essential role in keeping the system ‘on track’. Applying the systems perspective to the Glenorchy debate suggests that ignoring the evidence in the Glenorchy sewerage debate indicates a blocked (or absent) information feedback loop. Mechanisms for reinstating feedback are needed.

This paper attempts to reopen the feedback loop for sewerage technologies by building an information processing structure that connects the evidence (95% of the nitrogen in sewage comes from the toilet) with the decision makers and the council administrative framework. Information conduits are proposed as a thinking tool for identifying carrying mechanisms for getting this evidence-based information to the decision maker. One aspect of this information conduit is to find mechanisms that put the evidence in a form that the human brain finds easier to respond to. This helps the evidence to be heard through the cacophony of social processes.

A useful mechanism for carrying this sewerage information is argued to be via the dwelling rates. While setting up a rates-based mechanism necessitates council involvement, once set up this mechanism can achieve its information carrying role with minimal interference from either institutional, or social processes.

In reopening the feedback loop and allowing all the information and the interconnections to exist then considerable potential is released. This potential includes ways in which toilet waste capturing technologies can coexist with a conventional sewerage system, and enabling elements such as food security on a densely populated planet to be considered in the preferred technology.

In a highly interconnected world that is experiencing environmental consequences from previous technology decisions, the mechanisms proposed here need to be given space to exist so the information feedback loop can be reopened, better quality debate occurs and more appropriate technologies developed.

2. Overview

Given the complexity of both: Nature and human systems, then how do we cope with this complexity to enable the best decisions to be made? The best decision will, of necessity, include information from Nature's behaviour, our environmental effects and human social and economic information.

The task for this paper can be captured in the Glenorchy example of our decision regarding our wastewater (for which a centralised sewerage system is one possible solution). Glenorchy is beside a lake of 'significance' for tourism which elevates the need to reduce nutrient discharges from the town's sewage. This debate is occurring within the wider political context of NZ which is suffering deteriorating river water quality (our rivers are becoming unswimable). This environmental context occurs within a governing legislation that defines sustainable management (Resource Management Act), from which the council focus is on reducing **nitrogen** discharges to Lake Wakatipu.

The town also has a large development based on sustainability, and has recently completed a visioning forum that resulted in **sustainability** being the biggest 'wordle' (the term most frequently used when asked to: "provide two words that you would like to see included in a short aspirational vision statement for the Glenorchy community"). With this social context, it would be reasonable to expect sustainability to form part of our sewerage infrastructure debate.

Sewerage is however a mixture of urine, faeces and greywater and there is evidence that 95% of the nitrogen is in the urine and faeces – and this is supported by measurements of greywater nitrogen levels which are well within proposed discharge limits for nitrogen. With this evidence, the possibility that excessive N discharges to receiving waters can be solved by capturing toilet wastes separate from the greywater needs to be within scope. Indeed, technologies to achieve this are available and some of these (compost toilets) are being installed in the town's development mentioned above. These technologies also use less water and less energy so could be argued to be *highly* desirable from the sustainability perspective. However, this evidence challenges the very notion of sewerage (which uses water as a transport mechanism and requires all three to be mixed). In addition, sewerage systems have many decades of technology development (Benidickson, 2007) and cultural elements have evolved by which the general population's perception of 'sewerage' is influenced (this social preference for a particular technology is known as path dependency) – a hostile response from the industry to the nitrogen evidence can be expected.

It should not be surprising then that when the logic inherent in this evidence was made available to council and residents it was not absorbed into the public debate. This lack of response raises the question as to why (given the town's context and the intent of the governing act outlined above) this evidence was not given space?

3. Information as an explanation of real world behaviour

In the real world we monitor the bath as it fills with water and turn the taps off when there is sufficient water depth – water depth in this case is highly relevant *information* to our need to turn the taps off. If we don't respond to the water depth then eventually the water will overflow and make a mess on the floor. In the real world this information is largely experiential as we know from experience what different water depths feel like – and perhaps the frustration of overflow if our attention is diverted and we forget to turn the taps off.

There is however, another form of information that we could use to know when to turn the taps off. Using this other form of information we could *measure* both the volume of the bath and the flow of water from the taps. We could use this form of information to determine the *time* needed to fill the bath to the desired depth and use a timer to sound a warning if we forget the bath is filling.

The real world experiential-based information is very useful where the necessary response (turning the taps off) is closely connected to perceiving the real world information (water depth), but is limited in responding to processes that have long delay responses (such as if the flow of water was so low that several hours were needed to fill the bath), or the causes are not closely related to the effects. However, long delays and disconnect between causes and effects exists in many areas of human existence. Of particular relevance here are: technology development and pollutants building up in our environment. For these sorts of issues, the experiential-based information processing is less effective. These long delay and disconnect issues need a different information processing system from our real world experiential-based system. Part of the problem is that the human brain has a long association with experiential-based information processing but only recent exposure to a numbers-based information processing system. The result being that any numbers-based evidence that appears to contradict our experiential-based perception of how the world works is not given due weight.

4. Locating constraints to the information flow

Using information it is convenient to consider the lack of response by council and community to the evidence mentioned above as indicative of an *ineffective feedback loop* from a system's analysis perspective[1] – the information is present but something is preventing it from fulfilling its role of moving the technology towards less energy, reduced water consumption and nutrient recycle. A healthy system with a functioning feedback loop would respond to this contradiction between what is possible and what we have.

Before identifying mechanisms for establishing feedback loops, there is a need to more clearly identify the constraint to the information flow. Resolving these constraints are excellent 'leverage points' by which to influence the behaviour of the system. A small change (such as removing the constraint to the information flow) at such a leverage point has a major influence on the system outcomes.

To locate this constraint begin with perfection, that is Nature's evidence – the physical and chemical characteristics of the three waste streams in the case of the example being explored here and trace the information's path until it (or the consequences of it) enters the public discussion. The constraint is where the information is extinguished or blocked. For example, the beneficial consequences of separate treatment outlined above are extinguished when the three streams are mixed – eggs can't be reassembled from an omelette. In Glenorchy's case, nitrogen is the top priority and *toilet waste capturing technologies* (TWCT) would be at (or close to) the top of this sorted list if the above evidence is allowed to express.

Yet these technologies were **excluded** from the public debate of possible solutions. However from the information context being used here, the technology at the top of the list may only be deposed with new (and credible evidence). This evidence does not exist, so it would seem that it was human prejudices or preferences (or some other part of human functioning) that suppressed the feedback

[1] A system is a set of things – people, cells, molecules, or whatever – interconnected in such a way that they produce their own pattern of behaviour over time. Systems analysis considers complex system's behaviour to be primarily influenced by information carried in feedback loops, balancing loops and reinforcing loops (Meadows & Wright, 2008).

loop. To be effective, any mechanism will need to avoid this information constraint and ensure the evidence gets *through* this barrier.

A component of these cultural limits is nicely contained in comments made by many people to this author that can be summarised as: the logic arguments (arising from the evidence) need to link to emotional triggers so that at least they entered people's consciousness. In effect:

- This means that responding to the evidence is limited by the availability of words (or other emotional triggers) to carry the information to meaningful parts of the brain – any technological newcomer is disadvantaged by this communication constraint as the necessary terms are not yet part of the cultural milieu and its language. This is not so different from the 'talking past each other' effect that is well documented in interpersonal and intercultural relations; or indeed the insights of the social change mechanisms of Gladwell[2].

However this author was of the sentiments that logic should be able to stand ***alongside*** these human emotional triggers so the logic need never be compromised by the constraints of language or the cultural norms.

Indeed, if the constraints are so deeply embedded in human functioning then why even **begin** to try to understand it using language[3].

The task for this paper therefore becomes investigating mechanisms that can carry the logic into the public debate by:

- Improving the science interface to enable the evidence-based logic to enter the public debate without the distortions inherent in using the limitations of the spoken language and its cultural context. In effect, find a mechanism whose language: *shares some of the same properties as the phenomena under discussion*[3].

What follows is an attempt to build an evidence-based information processing system for dealing with our faecal and water wastes that also considers how our brains work, and consequently how this evidence-based information could be put in a form that is given due consideration in the human brain.

5. Constructing information carrying mechanisms within the Nature: human interface

A technology that utilizes Nature will exist at the Nature: Human interface. This interface, however, is extremely complex and we cannot assume that current technologies are the only ones that are possible. Both Nature and human civilisation contain their own complexity. In the case of Nature, micro-organisms, plants and animals are arranged in a plethora of ecosystems; while for humans we have evolved commerce, institutions, laws, politics and an economic system that is pervasive. In diagrammatic form the task can be seen as finding ways through a **wall of complexity (**Figure 1**)**.

[2] "We throw up our hands at a problem phrased in an abstract way, but have no difficulty at solving the same problem rephrased as a social dilemma. All of these things are expressions of the peculiarities of the human mind and heart, a refutation of the notion that the way we function and communicate and process information is straightforward and transparent." (Gladwell, 2013, p. 257).

[3] Systems analysis has this to say about words: "Words and sentences must, of necessity, come only one at a time in linear, logical order. Systems happen all at once. They are connected not just in one direction, but in all directions simultaneously. To discuss them properly, it is necessary somehow to use a language that shares some of the same properties as the phenomena under discussion." (Meadows & Wright, 2008, p. 5).

We need to locate the most relevant information from both sides of the complexity and allow this information to influence our technologies.

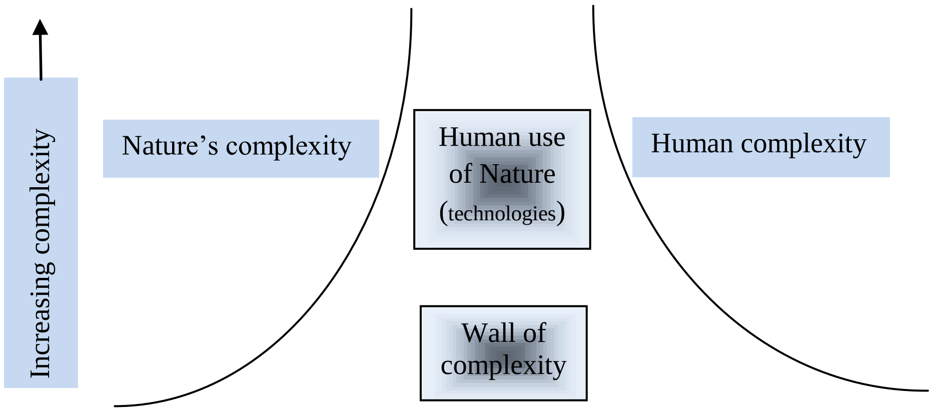

Figure 1

This separation of Nature from human in information space enables the **biosphere/human** component of the information flows to pass **through** the technology. Consequently, the trajectory of the *natural and physical resources* through the great planetary cycles can become part of the technology considerations. The potential in having several of the planetary cycles (atmosphere, biosphere, or lithosphere) to choose from is clearly greater than using primarily the water cycle to dispose of 'our wastes'. Indeed, these planetary cycles would rather they were called resources than wastes.

On the Nature side of this complexity, science has derived many mathematical formulations that 'carry' Nature's information and these can be assembled into models; resulting in Nature having a very good information carrying system.

For human use of Nature's information the interface task is reduced to the manner of human interaction with the evidence arising from these mathematical models. To assist this task, there are five 'paths' through this wall of complexity that are useful for the human interface:

- *Zero* is understood in the human domain in the same context that mathematics uses it. Zero is particularly useful for sustainability questions as:
    - It provides a datum for measurement of a technology's performance such as zero energy, zero water use etc. Technologies can be prioritised using these measurements and the best compared to what is possible – leaving space for yet-to-be-developed technologies.
    - Zero is the slope of the minimum in the first derivative of a set of equations. This is a useful mathematical version of a sustainability minimum – but this particular application would have little significance in a public debate.
- *One (1)*. The first of the whole numbers is an individual in the human domain so *one* has the same meaning in both contexts. However, within the human domain, the i^{th} individual (and their associated behaviour patterns) is linked to measurements of consumption of natural and physical resources (and any other individual-specific information). By using this individual-specific data, all the variability within the human population becomes available for

consideration. Using an individual in the analysis also establishes linkages to geography, as the individual has a geographical location **-** even if only for a short time period; so individual also includes tourists who would have a different set of data from permanent residents (while a tourist's *daily* data may be similar in magnitude to residents, this is likely to be spread over a wider geographical area).

- *Equals*. Equality has deeply held significance for humans (tensions arise if too much **inequality** arises, so equality is arguably necessary to operate as a successful social animal). Equals has its own mathematical symbol (=) so can traverse both human and Nature. Fairness can be viewed as an acceptable variability from equality and consequently is able to be used in both the mathematical and human domains.
- *Optimising parameters*. These arise when a mathematical model of Nature is solved for a human imposed value (such as odour production in the case of compost toilet technologies). Optimising parameters draw a surface through the wall of complexity that separates successful from unsuccessful technologies. They are particularly useful for commerce when designing technologies.
- *Information conduits*. In contrast to the technology specificity of optimising parameters, information conduits take the widest possible social context and enable comparisons between **all** technologies. They carry information to the most useful parts of human society in a form that is most likely to satisfy human needs by facilitating choice of the 'best' technology for meeting these social goals.

As zero and equals have both mathematical and human significance they can help make emotional connections between the evidence and the human brain and assist in an impartial debate. Zero is discussed in Chapman (2015b); Equals and its application to embedding fairness into a sewerage system in Chapman (2017b).

In contrast, optimising parameters have particular relevance for technology development so their public interface is likely to be indirect as their impact will manifest in improved technologies. An optimising parameter for compost toilets is proposed in Chapman (2011).

Information conduits take human needs and use these to set up mechanisms that enable particular information to be gathered from, and directed to, precise location(s) – they focus attention on the necessity for connections between the separate pieces of information. Information conduits are particularly useful for shaping the flow of information through human systems to achieve social goals. They can utilise the individual-specific data if necessary, and are the subject of this discussion.

6. Information conduits as a thinking tool for making the necessary connections

An information conduit's task is to take a set of social information (such as the need for improved water quality), the evidence (nitrogen concentrations and the technology implications resulting from this), and find mechanisms by which society can utilise this evidence and move towards some sort of 'best technology' to satisfy these social needs. All possible ways of using the data are available, leading to the implicit assumption that some notion of 'best mechanism' will also exist (as indeed is the possibility of several mechanisms operating concurrently).

Taking the initial social need, it is essential that the information conduit include **all** of the relevant information necessary to distinguish between all possibilities that could satisfy this social need.

Therefore to enable the information feedback loop, any mechanism formulated to satisfy the social constraints of an information conduit needs to connect three essential parts:

- First, the evidence: In the case of Glenorchy sewerage, 95% of the nitrogen is in the faeces and urine which is < 1% of the total volume. A technology which mixes this highly concentrated N source with greywater prevents consideration of any benefit that may arise from this concentration, such as reduced transport costs. Any benefit needs to be considered before the relevant information is lost – better to leave the information in by delaying technology choice.
- Second, the technology decision maker. An individual will generally make technology decisions within a specific context (be it a dwelling or a corporate context). This context can be used as an attachment point for the information from the first point above.
- Third as council are involved in the decision process in Glenorchy then a component of any mechanism must satisfy their needs.

6.1. Gathering the information – Initial focus of the human need

For the information needing to be carried in any feedback loop, consider some technology questions that arise from observing the Glenorchy sewerage debate:

- First, technologies that deal with **only** toilet wastes are available but not widely used. This triggers a series of other easier solved questions such as: are they user friendly? What visual elements may be impacting their desirability? Or is it an example of path dependency (a technology that is currently out of favour socially – but otherwise technically perfect)?
- Second, in the Glenorchy debate these technologies were not advocated. This absence of advocacy points to a need to focus on social change mechanisms which includes how these better technologies can coexist with a sewerage system.

The first set of questions clearly sits with the industry and science. This is a task more suited to engineering and market research (for which existing social organisational forms provide these services); and the optimising parameters of Section 5. However, it may be necessary to send commerce clear information signals of society's need for a particular technology. If this information signal is absent then finding mechanisms by which this information can be gathered and sent in a form that commerce will respond to is a task for an information conduit.

The second set of questions however, is clearly within the social/political domain (primarily councils and their employees in the Glenorchy case). If this is a task that has already been allocated to council process then this process hasn't worked for Glenorchy and it needs scrutiny. However, it is a task well suited to an information conduit seeking to open feedback loops.

Advocacy is a set of information in a form that has meaning to a human brain. The task is generally allocated to those who have expertise however advocacy needs no allegiance to any particular group. Alternative information paths are available. Indeed, if an information mechanism can avoid social processes (such as the evidence being presented directly to the decision maker), then information conduits have the potential to cut through the messiness of this political/institutional process.

6.2. Making the connections in information space

For an information conduit to avoid the need for advocacy, yet preserve the nitrogen evidence, the information connections must include the fact that those technologies that can capture 95% of this nitrogen are based on the toilet (more particularly the water flush). This is the point at which the downstream consequences from these technology choices arise and the type of toilet that is installed is an individual choice as each dwelling will have one. It follows that for a feedback loop to be effective this information can only be preserved if the information conduit influences *individual* technology choices. The individual is a *high leverage point* from a systems perspective. Indeed, at the individual scale the inherent variability in personal technology choice and the role of this variability in social change mechanisms also becomes available for consideration. At the individual scale, an effective feedback loop and the lack of the need for advocacy are very similar if not synonymous.

In diagrammatic form the individual's role in the information flows is central as so many information connections go through the individual (Figure 2):

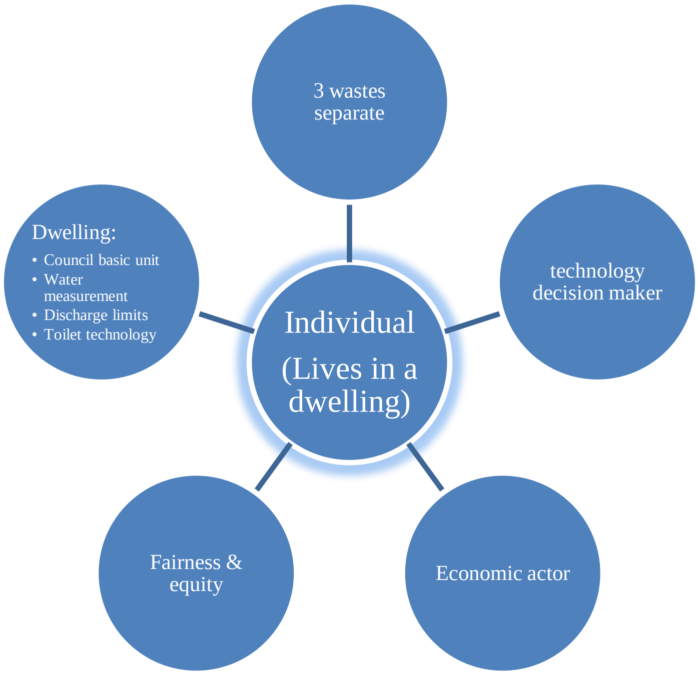

Figure 2 – Information connections that can be considered when formulating a mechanism using an information conduit. The close association between an individual, their set of values, the dwelling that they may own, and the technologies that they choose, makes this a high leverage point from a system's feedback-loop perspective.

However, the fact that this individual will live in a dwelling means all the necessary information connections can be made by directing the information through the dwelling and thereby connect with the council's functions and the legal frameworks that surround the dwelling (for a corporate decision this individual will link to a boardroom rather than a dwelling, in which case it also connects with council via the location of the company's legal title of its activity – which may be a premise that is leased). This forms an information connection between the evidence, the individual and community functioning (as influenced by its administering council).

Focussing the information flows through the dwelling then taps into considerable potential for resolving Glenorchy's information constraint as these technologies include the possibility of toilet waste capturing technologies – i.e. technologies that **prevent** N entering the water-based waste stream rather that **removing** it from the stream. Two additional advantages arise from using the dwelling:

- The council rating system becomes available to use as an information carrier.
- Being a basic economic unit that captures all the socio-economic variability in a community, a dwelling can also serve to build *economic well being* into considerations – the purpose of the governing Act is further enhanced.

All three information streams (the evidence, the decision maker and the council) are connected if any mechanism were to use the rating system to carry the environmental and social consequences of technology choices to each dwelling.

6.3. Getting the information into the human brain

It remains for the information conduit to ensure that any mechanism carries the **relevant** environmental information (nitrogen entering the lake in the case of Glenorchy sewerage considerations) in a form that achieves the social goals of reducing the flow of nitrogen into the lake. For a feedback loop to achieve this, the environmental impacts need to be in a form that the human brain responds to – they need to appear as a cost. Putting a monetary value on this environmental impact and passing this to the individual making technology decisions for the dwelling completes the necessary feedback loop without needing to make emotional connections in the public debate, or rely on council processes.

The debate can focus on fairness issues such as the relationship between reward (subsidy for N capturing technologies) and punishment ($.d/g N) – a debate that is perhaps more suited to the messiness of social processes considering that no individual can hide behind the masses if any measurement is based on the dwelling. The *tragedy of the commons* that Hardin articulated is avoided as each individual is dealing with the consequences of their own actions. When a mechanism is formed using an information conduit, the environmental consequences of adding another 'cow' to the commons (as used in Hardin's paper) appears to an individual as a cost that stands alongside the benefit. The information conduit's role is to balance the information signals to enable some sort of optimisation of the social and environmental well beings. For an overstretched commons, the **net** benefit of an additional cow would be negative. The signal points in the correct direction.

7. Refining the economic system connections to Nature, environment and human well being

Considering the pervasiveness of the economic system, then using this as an information carrier provides a readymade mechanism for accessing the decision making parts of the human brain. However, in order for economics to function as a feedback loop in information space, two attributes are required:

- The necessary information must be present; and
- This information connected to the decision makers.

For the necessary information attribute, commerce both: manufactures technologies and participates in the economic system. The information in this technology is packaged as the cost and measured performance of a particular technology (Appendix A.1). Environmental impacts enter this commercial transaction as the minimum performance expectation of the technology. However, the social data in this two-part information package is limited (in a commercial transaction) to the ability to sell the technology, which is a balance between affordability and legal requirements in the case of sewerage technologies. This commercial framework results in all manufacturers aiming to meet the legal discharge standards with a minimum cost technology – there is little incentive to manufacture a different technology unless it can be done both: cheaper and overcome all the cultural obstacles to its use.

There is even less incentive to question the 'system' – the assumption of a water-based transfer system in the case of sewerage.

However, if a feedback mechanism were to place more robust social and environmental information into this financial transaction, then the possibility of techniques other than legal coercion arise to effect improved environmental and social outcomes.

There are numerous ways this mechanism can operate. For example, the council discharge standards can be used either positively or negatively to add a monetary signal to a technology. This signal can be determined from the cost/performance information for the current technologies and added to the capital and/or operating cost of the technology (capital cost about $275 ($.d/g) N for the proposed Glenorchy sewerage scheme). By using current technology's costs and performance then the **actual** cost of **removing** the environmental impact becomes visible. It is not difficult to determine any technology's performance relative to these discharge standards and either charge for each gram **above** these standards[4] or give a suitable credit for choosing technologies that perform **better** than the standards. Information in this economic form has little difficulty accessing the mind of the technology decision maker as reward and punishment is the way we teach our children – the evidence can co-exist with human decision making.

Indeed, the possibility emerges of changing the value in this reward/punishment mechanism as a more cost effective alternative to using the law courts to influence environmental degradation. Both social and environmental benefits are possible from the same mechanism.

Less direct linkages to the economic system can be considered. For example, if zero energy, zero water use and nutrient recycle were a part of this feedback loop then the gap between current technology's performance and what is possible becomes apparent and enterprising businesses would seek to gain advantage by searching for technologies in this commercial niche. In effect, proximity to zero quantifies this information in a form that commerce can respond to by identifying an aspirational technological possibility. In addition, if any information mechanism also created a demand for technologies that are closer to zero then this is a language that commerce can understand. Profit is a powerful driver for commerce but needs both markets and technologies that work. Indeed, this type of information structure is very close to environmental impacts being formulated as those parts of the great planetary cycles that are not completed within the technology (mentioned in Section 5).

With the information in a form that encourages commerce to respond, then a vehicle by which environmental data can enter the boardroom becomes possible.

Indeed, putting a monetary value on all the social and environmental information does not exclude mechanisms of social change in this signal. Individualising this information (via the dwelling in the case of sewerage) then makes the information available at the **scale** that social change mechanisms operate, and this occurs **outside** of the public debate. In Glenorchy's case the 'hard' information of nitrogen content of faeces and urine would not need to be mentioned as people would be responding to the $ value they would be expected to pay/receive. The nitrogen information is embedded in, and carried by, the $ value that is charged to (or refunded from) the dwelling rates. Those who chose to capture their toilet wastes could make their decision independently of the general population and have their decreased environmental footprint acknowledged – the role of social change mechanisms (primary adopter, new technologies etc) is enhanced by this structure.

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[4] Readers may wish to consider the consequences for a manufacturer of a 'cheap and nasty' technology who has compromised performance to gain cheapness if their price advantage disappears.

8. Refining the social domain attachment points in information space

In the information world all the information streams connect to the atom. Engineering, microbial processes, laws of physics, technologies and individual variability in chemical components of their waste streams are all interconnected at this level. The possibilities emerging from this interconnection in information space that can be applied to the social interface are considerable. Some examples of these possibilities:

- There is a logic connection in engineering between the size and cost of a sewerage treatment station and the volume and pollution 'burden' being sent to it (burden includes the 95% N, the 50% of the BOD_5 and the other parameters such as Total Suspended Solids (TSS) that come from the toilet). This evidence -based logic can be used to refine the relationship between the dwelling technology choice and their capital (and operating) cost contribution for the sewerage system (Chapman, 2015a).
    - Further useful divisions can be made by separation of the reticulation and disposal systems from the treatment system; with the treatment system further divided into primary, secondary and tertiary treatment processes (Chapman, 2017a). This is particularly relevant for nitrogen as its removal is mostly a task for secondary treatment.
- Use the measured performance and cost (Appendix A.2) to sort all technologies from best to worst. Social processes can then determine where on this continuum the community would prefer to be. Then find a way of getting there.
- Equitable is a very powerful emotion linked to human values that can be applied to measurements. Indeed, when equals is applied to volumes and treatment 'burden', equity neatly accommodates all of –technology differences, current versus future residents (taking care of the problem of future developers being perceived as being subsidised by current residents), and commercial versus dwelling (Chapman, 2017a). It is very easy to have a high quality public debate around fairness and equity, then use this outcome and its logic connections to volume and treatment burden to allocate costs. Technologies for measuring volume are readily available. Treatment 'burden' is more difficult to measure but differences can be adequately accommodated by consideration of the variability difference between technology types - discussed further below.
- For a community in decline then $money_{in} < money_{out}$. Technologies have a cost and an owner. The choice of technology (and who owns it) will influence the rate of decline of this community. Indeed income generation from recycling the nutrients in faeces and urine holds the possibility of reversing a community's decline. $Money_{out}$ can be further reduced with some technologies as non-flush toilets reduce water consumption and consequently the water costs charged in their rates.
- The same framework can carry any or all of the *natural and physical resources* (water, energy, nutrients); with the priority *natural and physical resource* being set by the community's local environment.

When working with information other social goals can be included in considerations:

- Nutrients (the same ones causing problems in our rivers) are required to grow food and biofuels. The nutrients in the food we eat are mostly excreted in an adult so there is an information connection between the source of the nutrients needed to grow food and the technology we chose for our toilet wastes. Indeed directing the N from our faeces and urine to food production (rather than our rivers) and completing the great planetary cycles through the biosphere would seem to be a no brainer in a world that is becoming over populated. But it requires a technological rethink; which in turn necessitates these technologies forming part of the public debate.

- Administrative efficiency. Consider the three major types of technologies available for treating sewage: Septic tank, AWTS, and TWCT + greywater. The performance measurements of each of these different types of technologies would have a mean and standard deviation that could be applied to each of the technology types. These means and their SD can be used in lieu of measurement as a more cost effective administrative tool as it only requires a one-off inspection to ensure the technologies are installed. For example greywater only, is so far below discharge standards for N that no regular measurement is required to know this.

Paths through the complexity barrier are indicated that in effect separates the relevant information from the irrelevant information. By using social needs to shape an information conduit and forming mechanisms that preserve relevant information to satisfy these social needs, leads to identifying constraints to the flow of information. These are high leverage points in the system feedback loop. Enabling the information to flow to these high leverage points is likely to be the most cost effective way of improving social functioning. In effect, the environmental consequences of technology choice can be fairly heard through the cacophony of social processes.

9. Discussion

The notion of opening information feedback loops as a means of influencing the behaviour of complex systems, and identifying high leverage points as a focus for those small changes that have big effects is worthy of deeper consideration.

Within the above discussion, there appears to be some robustness about the ease of locating these high leverage points. This robustness appears in the range of different approaches used above that each leads to the same high leverage point in information space. In summary:

- The results of measuring nitrogen in each of the 3 waste streams and the consequences of technology choice on the nitrogen concentration in wastewater (Section 2).
- The constraint to the information flow that occurs when the waste streams are mixed (discussed in Section 4). Necessitating consideration of non-water based technologies.
- The role of advocacy discussed in Section 6.2 and an individual's perception of, and reaction to, this information that facilitates the development of technologies that consume less *natural and physical resources*.
- The role of scale that is set by the toilet technology that coincides with mechanisms of social change (such as the role of primary adopters and the *connectors and mavens* of Gladwell (2013)).

There are other discussion points raised in, and closely related to, the above that indicate dysfunctional elements in current systems:

- The lack of a response to the evidence by council staff; even though sustainability is clearly mandated under their governing act.
- The lack of response from councillors to the evidence. Indeed a frustrating circular argument was noted between these two areas of responsibility that neatly avoided addressing the

consequences of the evidence. Staff would say it is a political issue, while the politicians would trust the advice of staff over contradictory evidence.

- The commercial environment which has structural obstacles to development of technologies that do not require a water flush (noted in Section 7). This commercial environment can also be extended to council contractual procedures and associated lobbying (elements of which were present, but not conspicuous, in the Glenorchy debate).
- The implicit discrimination that needs to be invoked to 'force' a dwelling that has toilet waste capturing technologies, to pay the **same** capital and operating costs for the community sewerage scheme as a dwelling using a flush toilet – even though the volumes and treatment 'burden' are less. This under the guise of administrative convenience (which also resists consideration of alternative non-measurement based administration tools).

It is worth noting that removing these dysfunctional elements would also lead to the high leverage point based on the type of toilet technology and who makes the purchasing decision.

There is another component that arises from the list of different approaches mentioned above. Consider the interconnecting sequence that arises from allowing the evidence (and the technology implications) to be heard → leads to the stimulation of new technology development → trigger social change mechanisms that result in these new technologies being more culturally acceptable → feedback to faster technology development. That is, this is a *reinforcing feedback loop* where opening the initial information flow affects other feedback loops so the combined effect is larger than the original. This is all triggered (in this case) by a tiny piece of evidence and an open feedback loop. An added benefit from the operation of this reinforcing feedback loop is that the dysfunctional elements noted above also eventually disappear as a part of the information flow from this feedback loop will be heard by councillors and they will (may) make different decisions as a result – enabling even faster change to new technologies and difficulty for staff to hide behind the 'expert' argument etc. Not to mention the scrutiny of a more informed community.

Locating these high leverage points does not require a high precision nor complex analysis; it only needs consistency with the evidence. It follows that finding mechanisms that enable the evidence to be heard (and make it harder to ignore) is a good systems tool that is likely to be highly efficacious. Indeed, why even bother with the messiness of social processes when the evidence can be sent directly to the decision maker. Such a path is shown to be possible using a mechanism that puts a value on removal of nitrogen and using the council rating system to carry this information to the technology decision maker (the individual who owns the dwelling). There are likely to be other paths.

It could even be argued that with open feedback loops, healthy system functioning is a more natural property of social systems, especially considering that the dysfunctional elements noted above need to be maintained by force (coercion, intimidation, invoking authority etc).

It should also be noted that all the above requires only a measurement of chemical concentrations of each waste stream before they enter any technology. The arguments apply equally to all technologies and this enables this information feedback approach to **bypass** the role of expertise (expertise tends to be technology specific and accorded higher value without the realisation that it is very specific – this effect was present in the Glenorchy debate). This should also make an information approach easier to understand in the public debate; yet the Glenorchy experience suggests that this is not perceived as easy by the community. Perhaps our human brain just doesn't want to consider this; or we haven't developed the cultural context that is necessary (mentioned in Section 2).

In the above information approach, there remains an assumption of consideration of type of transport system (water or other). This arises as movement of molecules is pervasive within the great planetary cycles (through the biosphere, atmosphere and the water cycle) and as our technologies form a part of these larger cycles the movement of these molecules while within our technologies remains a consideration (which may be reduced to walking distance only if we dig a hole in the forest). This information connection to transport however can be used to improve the technology design as the role that our technologies serve within the wider planetary context can include the atmosphere and biosphere (food and energy) alongside the water cycle. Including also the source of the energy (carbon footprint) needed for transport.

Council installed sewerage systems are natural monopolies and have surrounded themselves with industry training, coercive legal frameworks etc that resist scrutiny. However, beginning the analysis pre-technology and setting up mechanisms for getting the information to the decision maker in a form that they consider in their deliberations sets up a structure that can only be challenged by evidence – i.e. **not** human values. This information processing system can therefore **stand alongside** the formal social mechanisms (council, industry, commerce) and serve as a continual challenge to the current way of doing things. This creates a means by which any excesses of this natural monopoly can be scrutinised – so long as the chemists remain independent.

The information connections of Section 8 are worth mentioning again as the possibility that, with a little more thought, we could consider the notion of optimisation of all of:

- Fairness and equity (remove any implicit discrimination, polluter pays, current v's future residents etc).
- Social change mechanisms – develop better technologies for future generations.
- High quality public debate of complex issues by information packaging and making full use of all the 'paths through the wall of complexity' mentioned in Section 5.
- Our technology's role in the great planetary cycles.

Then we would have a really good society.

Indeed, the social systems and technologies that deal with our waste streams would have a different trajectory over time and would look radically different in the future if the information feedback loops were open and fully functional.

10. Conclusion

There are a number of ways in which the Glenorchy sewerage debate could have been improved; but all trace back to the evidence needing to be heard through the cacophony of social process (which includes, in Glenorchy's case, council shenanigans). There is a need to connect the evidence with the technology implications of the evidence and allow this to influence the decisions. With nitrogen being the main environmental concern for Glenorchy and most of the nitrogen being sourced from the toilet then toilet-waste-capturing-technologies need to remain within scope in any discussion.

The individual emerges in this analysis as a high leverage point as they are the technology decision maker regarding the type of toilet (the point where the three waste streams are mixed). Indeed, a high quality public debate could be had using socially meaningful terms such as fairness and equity within the context of individual responsibility for removing their environmental burden. Unfortunately, the potential inherent in an individual's choice of more sustainable technologies has been extinguished with the natural monopoly of a community sewerage system as communal systems only need averages for design and operation.

The loss of information in this averaging process turns out to be critical – particularly the widely different N concentrations and volumes of each waste stream as it is from this variability that the technology consequences arise.

The development of an information feedback loop by monetising the cost of removing N from the waste stream and feeding this information to the decision maker who owns the dwelling via the council rates is proposed. This enables everyone to make their own technology choice and pay appropriately for their share of the community sewerage system (if this goes ahead). This is both fair and reasonable and enables individuals to choose innovative technologies that treat a portion of the pollution burden onsite if they wish.

To open the feedback loop, information conduits are proposed as a thinking tool for taking the social need (nitrogen into the lake) and making the necessary connections between the evidence, the technology decision maker and the council legal obligations.

The information carried by the opened feedback loop is effective in this case as the source of the evidence is the state of each of the 3 waste streams before they enter any technology, this enables a fairer comparison of the full range of technological possibilities. The reduced influence of both the cultural baggage surrounding an embedded technology (water-based sewerage and centralised treatment) and reducing the need for technology specific expertise, results in a more balanced debate. The weaker signals of community values can be heard and contribute to technology choice. This is a useful counter to any excesses that inevitably seem to occur within the political sphere.

However, for a community debate under the legal responsibilities of a council, the dwelling can serve as an attachment point as this is where the three waste streams are mixed and it will be an individual who makes technology choices for this dwelling. The mechanism for carrying this information is argued to be $ value added to, or subtracted from, their rates depending on the choice of technology.

We can make higher quality decisions that put the trajectory of the development of technologies for our waste streams on a path leading to the minimum use of *natural and physical resources.* We could be a lot more ‘sustainable’ than we are now and this can be greatly facilitated by opening the information feedback loops as discussed in this paper.

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11. Appendix

A.1. Formulating Nature's evidence to more easily enter the human domain

The human brain is most responsive to emotional triggers, yet science's language is mathematics, consequently any information carrying mechanism for Nature's information will primarily utilise numbers. An important component of an information conduit therefore is the need to enable an emotional connection with numbers (or the consequences that these numbers point to) so their information forms part of human considerations. The manner of the interface between this information conduit and the human domain consequently influences the efficacy of information transfer.

First consider existing information systems.

A.2. Information inherent in technologies

The performance of any manufactured technology can be measured and its cost will be known. Important from the information perspective, is that the measured performance is experimental evidence of the *net* effect of all the physical and microbial processes occurring within the technology – this measurement is consequently very information rich. However, it is not often used by the general public in their decision making.

The technology will also have a manufactured cost and, as money is pervasive in our lives, this provides ready access to the brain's decision maker role.

These two forms of information can be used either separately or combined, but they remain connected to a particular technology as a different technology will have a different performance and cost. The technology, along with its performance and cost, becomes an information package that can be used in any feedback mechanism.

A.3. The individual as an interface point of mathematical significance

Consider the range of different elements that attach to an individual from both the human and the mathematical domains:

- Human domain:
  - Individual lives within a culture.
  - Individual uses resources and generates waste.
  - Individual(s) make(s) technology decisions.
  - An individual is a basic economic actor with links to the economic system.
  - Particular individuals become significant change actors in society (Gladwell, 2013).
  - A dwelling houses a small group of individuals (which includes a family unit – an important social organisational form).
  - A dwelling has an identifiable location (legal title) in time and space. Time includes those dwellings which will be built in the future.
    - The dwelling is where the three wastes are mixed.
    - Mixing of the three 'wastes' extinguishes the possibility of separate treatment.
      - Consequently, technologies within the dwelling influence the 'wastes' emerging from the dwelling.
    - Dwellings occur on a legal title which is a basic organisational unit for councils.
  - A Community is composed of dwellings, commerce and public facilities.
    - Commerce: Employers of individuals and manufacturer of technologies.
    - Public facilities: used by individuals whose use patterns differ from locations where individuals spend more time (such as a dwelling).
- Mathematical/measurement:
  - $Community_m = \sum(individuals) = \sum_{n=1..m}(water_n, nutrients_n, ...)$.
  - All components affecting the behaviour of the **system** are present in, or influenced by, the individual; many of which can be measured (quantitatively or qualitatively).
  - Resources and waste can be measured and analysed as chemical components.
    - Energy attaches to mass so is also included in these measurements.
  - A distribution curve can be determined that adequately accommodates individual-scale variability – each individual does not need to be measured.
    - We can apply statistics and modelling, to this individual-based data enabling predictive analysis such as the environmental benefits that accrue from increasing numbers of individuals choosing alternative technologies over time.
  - As scale increases from the individual, the variability of the smaller scale is subsumed within the larger scale. Accessing information from the smaller scale is consequently also scale dependent.

From the information perspective, linking to the individual gains access to all the inherent variability of human behaviour including: resource consumption, waste production and, as we have to live somewhere, this individual also has geographical connections. There are no inherent assumptions or averages necessary to begin using this data – it is raw evidence. Consequently, when applied to the Glenorchy sewerage issue there is no inherent assumption of any particular technology. The nitrogen evidence noted above is preserved – all technologies are possible.