Enabling sustainability in the wastewater industry by finding space for primary adopters: Part II – Economic linkages.

P.D. Chapman

1 Introduction

Primary adopters are self-actuated individuals that lead change in communities. Part one of this series of papers showed that if these individuals adopted nutrient capturing technologies at their homes then they can initiate a path that leads to zero environmental discharges from our waste streams (an environmental discharge level *better* than a traditional sewerage system (Chapman, 2015)), if others follow their lead. Primary adopters are a useful agent of change for an industry that is in need of developing more sustainable technologies; particularly as industries (and cultures) are difficult to change. It follows that developing a non-hostile social environment within which these individuals can be nurtured means that they are at least *permitted to initiate* the changes that are necessary for society to reap these benefits over time. The magnitude of these benefits was argued in Part I, this paper looks at mechanisms to motivate these individuals with a particular focus on economic linkages.

To establish linkages to the economic system, volume is found to be a particularly useful parameter as volume links the underlying microbial kinetic to the size of container needed to hold the volumes. A further linkage to the **cost** of the container is possible by assuming a cubical container to hold these volumes and establishing a correlation between the surface area of this cubical container and its capital cost. Linkages to operating costs arise as thermodynamic laws determine the energy needed to move these volumes within the system design. The energy component of operating costs is therefore also strongly correlated to volumes.

Consequently an information link can be established between the biosphere and the human economic system. Volume is also a convenient administrative unit as water meters are being increasingly fitted to houses.

A range of economic linkages to capital and operating costs of a sewerage system are explored and these point to the ability to enable different treatment methods to exist within the traditional sewerage system. The visionary individual who fills the role of a primary adopter and initiates desirable changes can be given an economic signal to encourage innovation towards more sustainable technologies; to the benefit of future generations. Similarly, the individual who uses excessive water can have their adverse environmental impact quantified. Beneficial behaviour can be rewarded and detrimental behaviour penalised. This can be done without unduly compromising central collection of a community's waste water – the impact on a sewerage scheme is confined almost entirely to the treatment station; for which the possibility of avoiding the need for future upgrades is a highly beneficial outcome.

With economic linkages established, other useful social linkages become possible:

- The cash flow benefits from incremental improvements (relative to the one-off capital expense of 'doing' a sewerage system) are shown to be significant; leading to information linkages to the *purpose* of the governing Act: a community's *economic well being*.
- A mechanism to estimate the economic benefit of separate collection and treatment of each of the three waste streams is explored by comparing total surface area of the three individual containers with a single end-of-pipe container. This subject is addressed in more detail in another paper (Chapman, 2014a).
- The same maths shows that the cost benefit of increasing scale (as measured by cost/person as population size increases) is not as beneficial as we are lead to believe. With this insight, seeking a larger catchment area to support the capital cost of sewerage treatment upgrades cannot be assumed to be the only possible one, nor necessarily the best. At the very least it needs to be questioned.

An example calculation that puts a value on an individual who wishes to capture nutrients using a compost toilet is given.

2 Summary of Part I

In Part I (Chapman, 2015) the mathematical linkages between individual volumes, BOD_5 load, and nutrients were established using the underlying mass balance and arguing that a single first-order microbial kinetic could link all the components in a manner that preserved the patterns of behaviour of the system.

The first-order microbial kinetic used in Part I is: for a substrate concentration (S_0) and microbial rate constant (k):

Equation 1

$$S_t = S_0 \times e^{-kt}$$

There are a number of possible ways for society to interact with the underlying science; all these have the common characteristic that they carry information. The variation between them occurs in the type of information that is carried, where it is accessed and how it is used (Chapman, 2014b).

On the human side of this complexity continuum is the wastewater industry and its focus on a mix of all three waste streams – a historical legacy rather than a considered optimum type of technology.

It was argued in Part I that the emergence of sustainable technologies is hindered by this industry structure as collecting nutrients at their source (particularly urine) is demonstrably preferable to extracting them from a mixture of all three waste streams (Schonning, 2001), yet people willing to adopt such technologies derive no benefit in their rates bill. A consequence of this is that there is reduced incentive for commerce to develop sustainable technologies. A situation that is counter to the insights from social theories of change and, in a world facing increasing environmental issues, is a moral injustice if it isn't a flaw in the law. The information signals need to be consistent with the technology need. That is, based on the technology's efficacy not the industry norms.

However, human complexity is such that information signals are easily ignored, or do not survive being filtered through an industry lens. They are swamped in other information and hearing them becomes a political/institutional, rather than a logical process. At least until the physical manifestations (such as being unable to swim in rivers) force consideration of the environmental consequences – introducing a time lag into human response. There are consequently two issues needing to be addressed: a weak signal and elimination of the time lag.

A further consideration is that technologies develop over time and new ones need time to be refined before being suitable for widespread adoption. A system that is designed for changes over time can incrementally adopt these new technologies.

Bringing time and individual variability into the analysis enables the considerable creativity that is inherent in human behaviour to be harnessed. It also means that it is only the information signals to those individuals most likely to effect change that needs to be strengthened, not everyone needs to 'understand'. This is a task not dissimilar to the role of statistics in separating the signal from the noise in an experiment; or indeed detecting the useful signal from the radio spectrum.

Considering that it is possible to quantify the effect of individual variability on a sewerage treatment station then there is a need to incentivise primary adopters to begin making the changes that will be needed by future generations. If the information signal only needs to be detected by *some* individuals then an incentive is an information carrier that can be targeted to these receptive individuals. The sustainability signals can be strengthened (by use of mass balance) and made visible by incentives. The industry can create space for primary adopters and give them appropriate signals to encourage them to reach out to these new technologies.

Economic incentives are considered in this paper.

Within the economic system, a household is an economic actor along with commerce. Formulating an information signal into an economic form not only accesses the primary adopter located in a household, but also creates markets within the industry's water-based system for improved technologies. This then harnesses the considerable power of the profit motive as markets are the reason for commerce's existence.

Using these information signals means the task for political processes also changes, as responding to environmental impacts becomes a matter of responding to the *rate of change* in the development of improved technologies – a matter that is more suitable for the political process as resources can increase the rate of change. This is in contrast to current sewerage systems that require a multi decadal time-frame commitment to the use of water as a transfer mechanism. With such a set-in-'concrete' commitment, the desirability of the water-based transfer method is difficult to question, effectively preventing any changes at this fundamental organisational level.

3 Linkages to the economic system

Using linkages between the parameters in Equation 1 and the economic system enables a cash value to be placed on the effect of individual variability on the system design. Volume is a useful parameter for this purpose as it links container size to both BOD_5 and nutrients (particularly nitrogen) via Equation 1 and water meters are readily available (albeit these measure water into a dwelling rather that the direct measurement of water into a sewer). It therefore becomes necessary to establish a correlation between volumes and capital and operating costs.

3.1 Capital cost

To enable insights into the effect of volumes on capital cost it is convenient to use two components: the tank cost and the excavation cost. Tank cost is strongly correlated to cost of materials, which in turn is correlated to the surface area of the tank (Figure 1); while the volume of the tank is proportional to the ‘excavation’ cost.

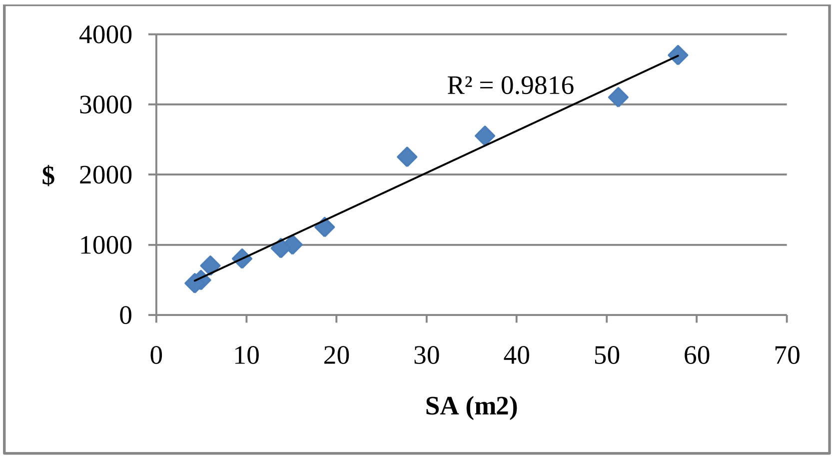

Figure 1 – The correlation between the cost of the tank and surface area (SA) of a cubical container that holds the volume (Equation 5). Note: 1/ that tank volumes range from 600 to 30,000 litres. 2/ that the actual tank geometry is cylindrical while this correlation is to its cubical equivalent, clearly with sufficient accuracy for the purposes of this paper. Data is for Devan plastic water tanks. Underground tanks have different regression parameters as they are built stronger, but the correlation between cost and SA still applies.

The container volume (V_{tot}) for a number of people (n) producing a daily volume (Q_p) of liquid that requires a residence time (t_r) in the tank for microbial degradation is:

Equation 2

$$V_{tot} = Q_p \times n \times t_r$$

The parameter (t_r) is very information-rich as it captures the considerable complexity of microbial processes within the technology (Equation 1) and carries this information into Equation 2. These microbial based interactions and behaviours were discussed in (Chapman, 2015).

However, to acknowledge individual variability, Equation 2 needs to be in a different form (Equation 3) where t_r in Equation 2 = t_r in Equation 3 only if the **total** BOD_5 loads are identical and the system is sufficiently well mixed that an average BOD_5 measure adequately describes the system:

Equation 3

$$V_{tot} = \sum_{i=1}^{i=n} (Q_i) \times t_r$$

If the total BOD_5 loads are not identical then t_r will need to be determined using Equation 1 where an averaging process determines a value for BOD_5 concentration (Equation 4). This can then be used as S_0 in Equation 1:

Equation 4

$$BOD_{avg} = \frac{\sum_{i=1}^{i=n} (BOD_i \times Q_i)}{\sum_{i=1}^{i=n} Q_i}$$

By assuming a cubical tank, then the necessary volumes would require a tank with a surface area (SA) of:

Equation 5

$$SA = 6 \times V_{tot}{}^{2/3}$$

To acknowledge individual variability then Equation 3 needs to be inserted into Equation 5:

Equation 6

$$SA = 6 \times \left(\sum_{i=1}^{i=n} (Q_i) \times t_r\right)^{2/3}$$

It is possible to determine a correlation between tank SA and its capital cost (Figure 1) and a similar correlation between tank V and cost of installation could be done. Both tank cost and excavation cost are parts of the total capital cost, however this would move the precision beyond the derivational limits of Equation 1 (and the cubical container assumption). Particularly as the **information** indicating an influence on costs will be present in SA. It remains to extract this information in a usable manner.

If an individual makes a change to their waste stream then this will occur at a point in time and the *proportionate* effect on the treatment station size can be captured by two time-separated calculations and dividing the magnitude of this difference by the total SA:

Equation 7

$$M_{change} = \frac{SA_t - SA_{t+1}}{SA_t}$$

Where: t+1 captures the change in individual behaviour as expressed through t_r and Q_i in Equation 6 when t_r is determined using Equation 1.

Multiplying the treatment station cost by M_{change} would put a cost value on the benefit to treatment station capital cost of the individual change.

3.2 Operating costs

To estimate the effect on operating costs it is convenient that volumes relate to energy cost via thermodynamic laws. As volumes can be individualised (at least to the household level) then individualised operating cost can also be built into the rates charges.

For the reticulation and disposal systems, energy is the most significant operating cost and energy is directly related to volumes. These energy considerations can be extended to water supply costs for technologies that use less water. For example, Glenorchy's proposed treatment station is 23 m above the town. Lifting each m^3 of water this distance requires a calculable amount of energy for which the costs of supplying this energy are known. In contrast, the treatment station operating costs are more complex with chemicals, energy and labour costs being dependent on the design. Some of the processes in treatment stations have direct energy linkages, particularly nitrification, for which the energy component relates to mass transfer of oxygen (Smith & Katta, 2000). Energy requirements (Table 1) can be further subdivided into: static head (mass (volume) and the lift) and dynamic head (pipe friction).

Sludge production, the costs of drying and reuse/disposal can all have analytical space within this framework by its thermodynamic linkages, in terms of drying, or Equation 1 in terms of carbon.

Repairs and maintenance in contrast are a part of operating costs that is most conveniently allocated equally across the community rather than on an individual basis.

Table 1 – The significance of variation in input loads (volume, BOD_5 and nutrients), on the energy requirement of operating a sewerage system. Energy requirement is the most useful parameter to acknowledge individual variability on operating costs as it is related to volumes and system design by thermodynamic laws.

	Reticulation	Treatment	Land disposal
Volume	Energy needed for: - Static head. Determined by volumes and lift. - Dynamic head. Affected by velocity, pipe size, pipe length.	Energy in moving mass.	Energy needed for: - Static head - Dynamic head
BOD_5	Unaffected.	Microbial processes utilise chemical energy in the BOD_5 (from carbon).	Unaffected.
Nutrients	Unaffected.	Energy for mass transfer of oxygen (needed for nitrification).	Plants utilise solar energy via photosynthesis. Mechanical energy needed for removal of biomass – may be an economic benefit rather than a cost.

4 System behaviour

Because all the relevant interconnections between the microbial growth rates, volumes, organic loads, and the container size are maintained, this simple model displays complex, yet deterministic, behaviour. It can be applied to any population size via the capital and operating costs of any technology that deals with the three waste streams, either mixed or separate, and get insights into the effect of individual variability on the system design.

The signal from Equation 7 is also inherently capable of detecting *detrimental* behaviour patterns. Particularly useful for this task are total volumes as these are readily measured with water meters, and volumes link to BOD_5 and nutrients via Equation 1. A high water use household for example with the same organic load would have a negative M and could be required to pay for the extra cost (Figure 2). In this case the reference volume is based on a person ($0.2\ m^3\ d^{-1}\ p^{-1}$) so some adjustment for numbers in the household would be required, but the flexibility of Equation 7 remains as the interconnections are unaffected by the size of the administrative unit used in the analysis.

This administrative unit would clearly need a large dose of pragmatism and cost effectiveness. It needs to be small enough that people are motivated to change. A group of individuals in a house may respond as this will show in their rates bill; in contrast to several houses (such as a development) where the signal may be too dilute to effect a change in individual behaviour.

Indeed, using volumes from water meters also captures the effects of occasional-use holiday homes; although the consequences for system design of holiday-period peaks in water flow is a confounding problem that would need resolution.

Water meters could also be fitted to public toilets enabling the possibility of attributing their costs to visitors rather than being a burden on rate payers; although the mechanisms for recovering these costs would be politically contentious.

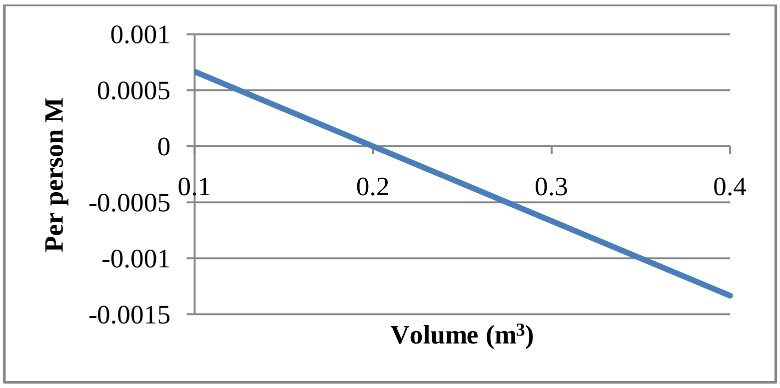

Figure 2 – Effect on M of variation in volume only while retaining the same BOD_5 load. Calculation based on a single person in a 500 person town; the system design allowance being 0.2 $m^3 P^{-1} d^{-1}$.

This method could also give insights into the number of community members that need to adopt full nutrient recycling to prevent an upgrade of an operating sewerage plant. In this case M would need to be 0 (no change in container size is required) and this would necessitate consideration of the *net* effect of several individual changes; a computational problem rather than a limit of the methodology. A different mathematical approach to the same issue using only nitrogen and mass balance is proposed in Part I of this series (Chapman, 2015). Providing incentives for these changes is an alternative to a costly upgrade, with the added benefit that easier nutrient recycling becomes possible. The community moves towards sustainability, while generating commercially useful signals re technology development.

4.1 Scale effects

Considering that the set of equations detailed above contain the population size (n) their individual contributions (Q_p, S_p) and that the rate constant (k) includes the biosphere, while the SA of the tank is linked to the economic system; it becomes possible to consider the effects of scale (arising from the size of population served (n)) on the cost efficacy of the various systems.

As each part of a reticulated system responds differently to the effects of scale they need separate consideration (Table 2).

Table 2 – The effects of increasing size of population serviced (scale) on the three components (reticulation, treatment and disposal) of a conventional sewerage system. Assuming: 1/ the volume per person is the same across the population; 2/ that costs are linearly related to total volume (V) (Figure 1); 3/ disposal is via land application for which an upper application limit is based on L/m^2 of land surface.

	Reticulation	Treatment	Disposal
Effect of scale	Pipe size (V) Trenching (length)	$V^{2/3}$	V
Approximate proportion of total cost	1/3	1/3	1/3

Apart from population density effects (that increase pipe sizes but reduce pipe length per person in the reticulation system), the treatment station is the only component of the system for which the scale effect of a larger population has an advantage in terms of costs (2/3 power of V). The scaling effect is strongest at volumes less than 7 m^3 (Figure 3); while doubling the volume from 200 to 400 m^3 only drops the unit cost 0.23%. However, as the treatment station is only around 1/3 of the total cost then the overall impact of the scaling effect is not great. Indeed decentralised systems are cheaper than centralised systems because concentrating on reducing the cost of the reticulation system (by enabling smaller pipes from less infiltration-inflow that can be laid closer to the surface) is greater than the loss of efficiency from the scale effect of using multiple septic tanks each serving a household.

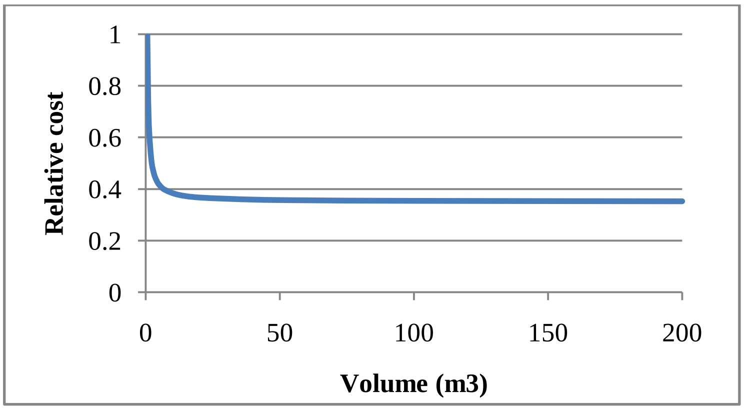

Figure 3 – The effects of scale (larger population generates greater volumes) on the relative cost of the container. Assuming a strong positive correlation between surface area of a cubical tank needed to hold the volumes and capital costs of the system ($=176.91*SA+163.59). Note: regression data is for 3 Devan *underground* tanks for which the max volume was 3600 L (r^2 =0.9546). While this regression is used beyond its derivational limits the same behaviour can be expected for 'actual' tanks, but with different regression constants (Figure 1). The increase in unit costs at very low volumes can be attributed to the +163.59 in the equation. Cost is normalised to 0.5 m^3.

It is possible to attribute the effects of scale to incremental changes in a population size by changing the subscripts in Equation 7 to total number of people (n) rather than time (Equation 8), and the individual increment is accommodated by n-1:

Equation 8

$$M_{person} = \frac{SA_n - SA_{n-1}}{SA_n}$$

Note that Equation 8 reduces to 1 if n=1 and as SA incorporates: individual volumes, BOD_5 (or nitrogen if the relevant rate constant is used) and the time required for treatment of the material; then all components affect the value of M_{person}.

The cost per person can then be determined by multiplying M_{person} by the actual cost of the treatment station needed for n people (Equation 9). The effect of increasing scale on the per person cost of sewerage treatment can then be determined by the slope of the *n* versus $Cost_p$ plot.

Equation 9

$$Cost_P = M_{person} \times Actual\ cost_n$$

Equation 9 effectively attributes the scale increment to the last person connected rather the mean of the total population. This is a more useful location from which to consider the role of primary adopters in a system utilising incremental improvements.

Equation 9 could also be applied to the cost of removing nitrogen from the waste stream, particularly as nitrification and denitrification typically use different containers (and denitrification would require a different rate constant). Basing this cost on an individual enables the cost efficacy of separate collection of urine (the source of 90% of the nitrogen in the waste stream) to be judged against centralised treatment. The cost of fitting urine separation toilet bowels needs to be compared with the cost of removing the equivalent nutrients at the treatment station.

If there is little advantage of scale in locating the treatment station at the end of the pipe, then the industry can begin to consider optimising the technology's tasks at the individual (or household) scale. If it is more cost effective to capture nutrients at source then these technologies should be encouraged.

For this role, the cost efficacy of each technology can be done for each task (nutrient removal, pathogen destruction etc) – this aspect is discussed in more detail below. This, in conjunction with incremental improvements, further enables the communities economic well being to enter considerations.

4.2 Cash flow considerations

A centralised system necessitates a large upfront capital requirement which, with interest, raises the cost considerably. For any community considering methods for dealing with their waste streams the *minimum cost* calculations need to include these interest costs and methods of reducing them. Incremental improvement is one way of minimising these interest payments. By way of example, a household facing a $20,000 capital expense using money borrowed at 6% interest rate would pay $1200 per year in interest before repayment of the principle. Indeed if this interest payment were used each year to upgrade the on-site systems that we currently have at each house, then in each year 6% of the houses could have a $20,000 upgrade; resulting in the whole town being upgraded in 16 years.

The formal method used for assessing the actual cost of this up-front capital expense is the amortized value (that is capital + interest spread evenly over the specified time period). If the actual cost of this capital expense is spread over 16 years (the same time period needed to incrementally upgrade the town using the interest alone), then the annuity is $1979 – an 'actual' cost for the household of some $31,664 over 16 years. By way of contrast, if this system was done in 4, $5000 increments with each increment repaid in 4 years then the amortized annuity reduces to $1442 – an actual cost of $23,087. This is a net economic saving for the household of some $8,577 over the 16 year period; or $537 per household per year.

It follows that this large up-front cost can be substantially reduced with a little more thought, and attention to the underlying science. Incremental improvement achieves the nutrient reduction goals over time and, there is only a need to combine this physical fact with social and economic behaviour to see alternative behaviours that have less of an economic impact. It becomes obvious that a single large expense necessitated by doing a 'sewerage system' all at once is the most expensive option (9.9% of the capital cost being required as an annuity over 16 years - Figure 4). This cost reduces to below 7% if the same scheme is done in 6 or more increments.

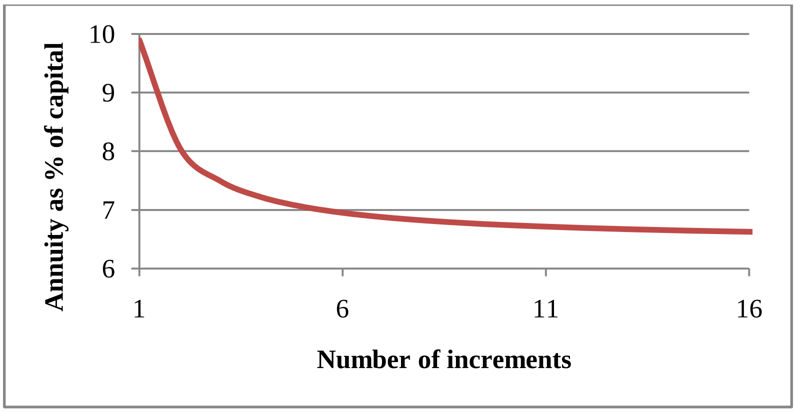

Figure 4 – The annuity as a % of capital cost where the work is done in a number of increments over a time period of 16 years; where a conventional sewerage system is a single increment. The time period of 16 years is the time taken if the interest cost (taken at 6%) of doing it in a single increment (this is a conventional sewerage system), was used to upgrade the infrastructure rather than be paid to the banks. This is, if 6% of the houses were upgraded each year then in 16 years all houses would be upgraded. The lower annuity (6.626%) is the minimum *annual* payment based on the capital cost per house if a full upgrade were done over a 16 year timeframe. For the $20,000 capital expense, discussed above, if done in 16 increments then some $1325 would be required from each house (this could be further reduce to $1187 annual cost if the time period were extended to 20 years).

With incremental improvements a community funding model becomes possible in which notions such as fairness and equity can be incorporated. In this scenario everyone can assist with funding each increment, but it would require a binding agreement that such a funding model would be applied to all increments. That is, a household assisting with funding the commercial sector now, but not being upgraded themselves for a number of years would actually receive the return assistance when their turn came. This would be less of an economic drain for the community as it avoids the need to source the large capital requirement, with the added advantage of leaving space for moving towards sustainable technologies in the future. Indeed information on the more sustainable option could be built into the community funding model – such as those which enable nutrient recycling having a higher community 'subsidy'.

4.3 Separating the waste streams

The separate treatment question is discussed in depth in (Chapman, 2014a). However, insights into the cost implications of separate treatment can be addressed using the maths detailed here. Sewerage is a mix of three components therefore mass balance laws apply and removing one or more of the components has a deterministic effect on treatment of the remaining mixture.

It follows that surface area (using Equation 6) can be separately determined for each of the waste streams. The linkage between SA and the capital costs of the necessary container (Figure 1) means the cost efficacy of separate treatment of each of the components of the waste stream can be estimated.

Equation 10

$$SA_{Separate\ \ treatment} = SA_{faeces} + SA_{urine} + SA_{greywater}$$

The difference between the $SA_{\text{separate treatment}}$ and the mix of all three (SA_{sewerage} - Equation 6) gives an estimate of the cost comparison of manufacturing a separate container for each component:

Equation 11

$$M_{Separate\ \ treatment} = \frac{SA_{Separate\ \ treatment}}{SA_{Sewerage}}$$

Without adjusting for residence time Equation 11 will give a value >1 as the scale effect of housing parts of the total volume in separate containers dominates. However some 44% of the BOD_5 in the mixed waste stream comes from the blackwater (faeces and urine); it follows that the shorter residence time that will be needed for treatment of only the greywater can be taken into account; as can the longer residence time required for the very high BOD_5 of faeces. Indeed Lindstrom (1992) quoted data pointing to the need for a different rate constant with greywater treated separately.

In addition, as pathogens are the main consideration for faeces and time is a useful parameter for pathogen control means that pathogen control requirements can determine the residence time and consequently the volume of the faeces container. For the better than *one year* time frames indicated in Feachem et.al (1983, p. 63) for pathogen control, the volumes per person are in the order of 50 L $year^{-1}$ so these time frames are possible within a reasonably sized container. This can be compared with residence times of only a few days if the faeces are mixed with the greywater.

To this mix of considerations can be added both:

a) the reduced flush water that is possible for some faeces only technologies (30% of total flow from the toilet flush - Feachem[1] et.al (1983, p. 18)) and
b) the urine (which contains most of the nutrients) can be evaporated thereby needing a smaller container than an analysis based on volumes would indicate.

Using Equation 11 with adjustments for residence time arising from BOD_5 of each component (a different rate constant is argued for greywater (Lindstrom, 1992)) and the lack of flush water that is possible with some faeces technologies, enables a cost comparison that is based on linkages to the quantity of materials needed to manufacture the respective container(s) – and by correlation to the *costs* of manufacturing the container that houses the technology (Figure 1).

In this author's view the pathogen question is the most compelling one for separate collection and treatment of the faeces as, with the small volumes involved, very long residence times are possible for little increase in costs.

To the quantity of materials and pathogen control arguments discussed above can be added the operating cost differences that arise from transporting nutrients in a dry form in comparison to the pumping cost of moving the very high volumes of water when these nutrients are mixed with water. Cost savings also arise from reduced water consumption, as the toilet flush can be eliminated.

This is a more useful position for considering future generations as separate collection of nutrients is demonstrably preferable to extracting them from the mixture; particularly considering the sub-optimum structure of the industry argued in Part I.

5 Compost toilet example

An individual installing a compost toilet and recycling all their nutrients will have an effect on the treatment station arising from both: reduced BOD_5 loads (44% removed (Lindstrom, 1992)) and decreased volume (as flush water is not required - taken at 30% - see note 1). Note: conventional

[1] Feachem et al's data was from two sources: Witt and colleagues 22-45% and Laak 41-65% - their mean value is 47%. Note also the data from a Swedish multi-story apartment building with ultra-low flush toilets at 7% noted in (Lindstrom, 1992). In contrast, (Ferguson, Dakers, & Gunn, 2003, p. 137) quote Christchurch data at 19%. The figure of 30% weights the value towards the New Zealand data, while acknowledging the high sample size quoted in the Feachem data.

flush toilets would generate a higher proportion of the total water volume, although the BOD_5 proportion is likely to be the same. Compost toilets also remove nitrogen from the waste stream.

For a 500 person town the proportion (M) from Equation 7 is 0.000451. If the treatment station capital cost were $5m then the individual's saving in **capital cost** by not adding the extra water and BOD_5 is in the order of $2000 – details of the particular community's system would be required for each system, but the principle of acknowledging the reduced costs of an individual taking responsibility for their discharges remains. To this could be added the reduction in **operating costs**, particularly the reduced energy requirement arising from the lower volumes.

This is a sufficiently high figure that some individuals may choose to invest in compost toilet technologies and recycle all their nutrients. Indeed, as nutrients have a tradable value then this economic signal could also be added to the mix of considerations that an individual can take into account.

Further to this mix of considerations is the reduced cost of operating the community treatment plant as sludge production is reduced. Sludge is a high cost component of operating the community plant, but a nutrient-rich resource from a compost toilet; indeed the author has won the largest pumpkin section in the local harvest festival for two years in a row when grown in compost from his toilet. There is also some intriguing evidence that an 85% reduction in sludge production is possible with removal of the toilet wastes[2].

Considering that, for the dwelling it is only necessary to know a/ there is a compost toilet and no flush toilet and b/ the water use can be verified by water meter; then the calculations only need to be done once (when the flush toilet is removed and the compost toilet installed). This is administratively convenient, particularly as any change in occupancy would appear as an increase in water use, and a change back to a flush toilet would require resource consent.

6 Discussion

When humans use Nature in a technology then both the complexity of Nature and the complexity of human systems are all implicit. It is easy to get swamped in the complexity of either side and miss the subtlety inherent in the interaction between the two. In order to extract the most useful information, the manner of human interaction with Nature becomes an important question – particularly when human societies change over time and must respond to emerging environmental issues. Within this context, incumbent technologies need constant scrutiny as to their efficacy.

There are many levels to which optimisation questions can be applied. Firmly on the Nature side of this preparation task are the arguments arising from mass balance laws that identify the possibility that improvements to nutrient discharges by incremental adoption of nutrient recycling technologies over time can achieve better discharge standards than the one-off implementation that is inherent in centralised sewerage treatment. In contrast, moving the analysis boundary on the Nature side to include microbial kinetics, brought in substantial spatial complexity for which using a simplified microbial kinetic was shown to preserve the system behaviour without getting swamped in the spatial

[2] Based on the assumption that 50% of TSS emerges as sediment and greywater (taken as 75% of the total volume) contains 40 g m^{-3} (Siggins, et al., March 2013) while sewage contains 200 g m^{-3}. At 0.2 m^3 d^{-1} p^{-1} total sewage flows, this is 6 g d^{-1} sludge from GW v's 34 g d^{-1} (40-6) from the toilet. Note this sedimentation % could be argued to be higher in greywater as soil particles with a higher specific gravity are more likely in greywater than in faeces.

complexity (Chapman, 2015). This enabled the pragmatism necessary to distinguish between different types of technologies to have a good scientific basis, and is used in this paper. For example, the consequences of an individual choosing a technology that removed half of their BOD_5 (along with some of the water), and the effect of this choice on the capital and operating costs of a centralised treatment station become visible.

These insights mean social behaviour questions can be both asked and answered.

On the human side of this complexity are a number of organisational forms whose needs are best met by particular formulations of the underlying descriptions of Nature's behaviour that target their major interest. The commerce sector that manufactures technologies can use a Nature-based parameter that is chosen for its social function (e.g. odour generation potential) so the product is more likely to be a commercial success (called an optimising parameter in Chapman (2011)). In contrast, the regulatory framework needs information in a different form. In this regulatory case, sustainability can be applied to the assemblage of the underlying fundamental laws and processes as the mathematical procedure of minimisation. As sustainability is the purpose of the RMA then any design that uses this minimised set of equations will contain this sustainability minimum and be more likely to produce the most sustainable possible technology. For the administrative tasks the 'beacon' (in essence a description of the constraints that the most sustainable possible technology will need to have – zero: water, energy and pathogens and recycling of all nutrients) can be supplemented with the information signals discussed in this paper in which environmental and communal benefits that arise from changes in individual behaviour can be recognised. The forms of information argued here are each consistent with all four of: the underlying science, the governing act, the communities that it is intended to serve and the commerce sector that will produce the technology.

Of particular focus in this paper is the social organisational form of the economic system, for which capital and operating costs are a component that must sit alongside the performance characteristics of each of the possible technologies. Because of the pervasiveness of economics, information linkages between Nature and the economic system have the potential to effect significant changes towards more sustainable technologies. Price signals attached to any manufactured technology are information rich in terms of supply and demand etc, else they wouldn't be manufactured; but information poor in terms of environmental impacts. Indeed the reason institutions monitor discharges, and the need for the establishment of the on-site test facility at Rotorua (Gunn, November 2014) is surely evidence of the inability of the current form of commerce to fully internalise these environmental costs.

When looked at from an economic perspective the cost efficacy of a centralised sewerage system is low. Not only does it have high running costs – it needs water and energy, its pathogen and environmental performance are poor (nutrients are not recycled); but also the very high up-front capital requirement, which is expensive and is largely unavoidable. To this detrimental economic impact must be added the long-term consequences of stifling incremental development. In effect everyone must be treated as an un-differentiable average in order for the system to work – or more particularly treated as a 'toilet pan' as this is where engineering begins. This has the effect of not only embedding a technology that fails many environmental indicators (energy use, water use, and nutrient recycling), but also stifles the creativity that is inherent in human behaviour as there is no benefit from thinking and acting differently. This does not need to be the case.

The role of primary adopters as a force of change is something that the industry would be well advised to embrace, rather than actively discriminate against. It is shown above to be possible to quantify the effect of individual variability in pollution loads and volumes, on the capital and operating costs of a sewerage treatment station, consequently primary adopters can be given the space to be different even if the community adopts a fully reticulated system.

Enabling individual variability to express then potentially generates information linkages to the well beings (particularly economic and cultural) of the RMA's purpose. This is a very high-level legal linkage which, with appropriate consideration, has the potential to become embedded within the decision process. In this location it is less able to be influenced by council machinations and consequently becomes a truer expression of the community needs.

7 Conclusion

Primary adopters are so called as they are the first to adopt new technologies. However, it is the effect they have on the people that surround them which is useful within the sustainability context as the incremental nature of the changes that they initiate can be shown to result in less environmental discharges over time – this was shown in part I of this series of papers using a mass balance analysis.

This paper takes the simplified microbial kinetic from Part I and investigates some of the useful linkages between individual variability and the economic system: particularly capital and operating costs of a conventional sewerage system. Forming linkages to the economic system means that incentives can be targeted to these primary adopters without the need to convince the whole population of the merits of a different technology. A number of ways of making these linkages are shown to be possible; so we have mechanisms by which the impact of individual variability (and personal choice) on sewerage treatment capital and operating costs can be attributed to a household organisational unit. Individuals that make choices that are more sustainable than others can be rewarded.

Complex behaviour patterns emerged from this simplified model that enables other insights:

- The effects of scale on the per person capital cost of treatment as the population size increases can be seen to be a comparatively minor consideration in designing systems for dealing with our three waste streams. A consequence of this is that enabling individual variability to express does not overly compromise the cost effectiveness of sewerage systems but substantially enhances the information signals that generate new (and improved) technologies.
- In part arising from the reduced scale effect, the cost efficacy of on-site collection technologies warrants closer attention, particularly as reuse of nutrients becomes necessary to grow the food for an increasing world population.
- With a little more thought, information linkages to a community's economic well being are possible – both reduction of costs and increasing income (from the sale of recovered nutrients) are possible.

The role of the primary adopter therefore can be nurtured and their information signal made available to the commerce sector to further enhance the development of sustainable technologies, to the long benefit of human sustainability on our planet.

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