Embedding fairness and equity values into a community sewerage system – mathematical version.

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1 Introduction

Any notion of an optimum technology for a community must begin with this optimum technology being within scope and it must remain within scope until the final decision is made. In the context of a community (and governing Act) that requires sustainability, then the optimum is that which: uses zero water, requires zero energy and recycles all nutrients. Those technologies closest to these zeros must remain in scope, even if they aren't eventually chosen. For a community considering a sewerage scheme than the first question needing resolution is: "is a sewerage system the closest technology to the sustainability zeros?" This question is addressed for the Glenorchy context of nitrogen into lake Wakatipu using the chemistry of each of urine, faeces and greywater. It is shown that toilet waste capturing technologies are closest to these zeros and need to remain within scope in the decision process; even if a community sewerage system is preferred for collection and disposal of its water wastes.

There is an underlying structure to this information processing that can be captured in the notion of widening contexts - Figure 1. This analysis also includes the role of commerce in generating technologies and the need to allow social processes to express as only a few individuals will make different decisions to the masses.

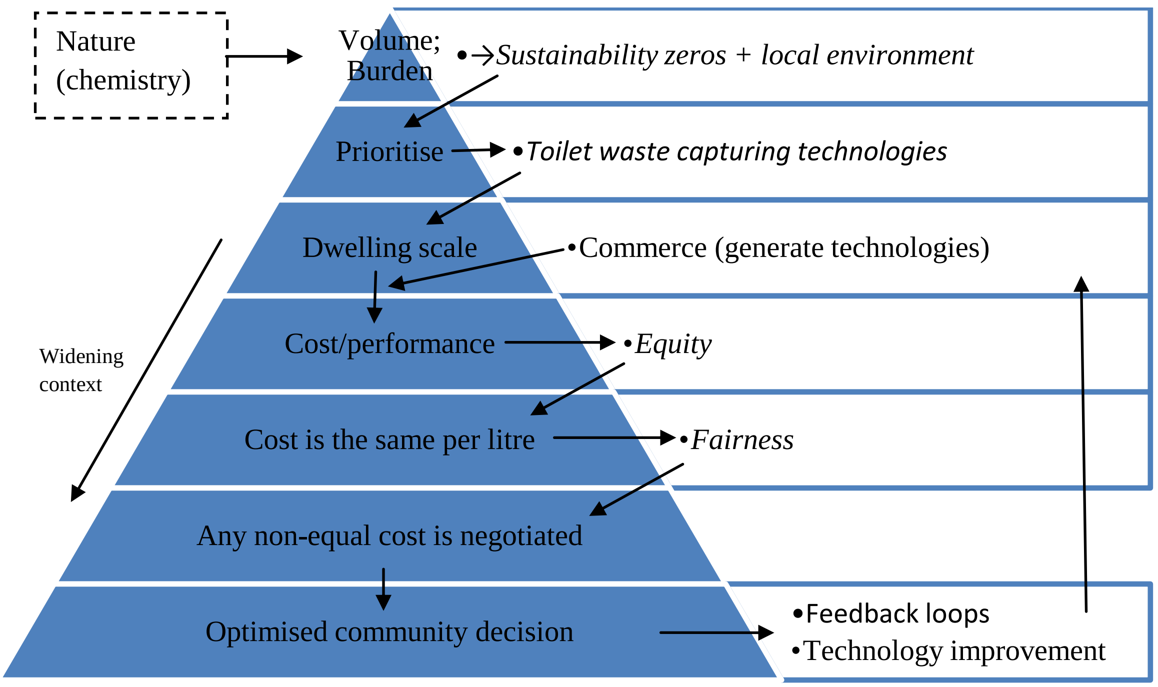

Figure 1

The approach taken here to ensure that toilet waste capturing technologies remain within scope as the context widens and includes a community sewerage system, is to search for mechanisms by which individual variability (in effect those primary adopters who will chose differently) can be allowed to express within the sewerage system. One possible mechanism is to reduce their costs by the value of the on-site treatment that occurs in their more sustainable technologies. These cost adjustments can be based on any of: volume, nitrogen or other measures such as BOD_5; or a mix of them all. Volume is the easiest of these to measure at the dwelling scale.

Fairness and equity values can form an important part of this process as equity is understandable to humans and also has mathematical significance. There is only a need to identify the parameter that needs to be equalised for equity to apply to all residents, commercial business and public utilities. Fairness then has a role in negotiating any difference from equity.

These mechanisms, based on the chemical components (particularly volume) and fairness and equity values, are shown to also cope with sharing costs between future and current residents. Developers (who provide section space for future residents) therefore pay their fair share of the capital costs. Also the costs of the differing volumes and Burdens of commerce are fairly attributed.

Despite the complexity involved, fairness and equity values can be accommodated in a community decision around technologies for dealing with its faecal and water wastes. The ‘best’ system for the community is that which is closest to the optimum, but acceptable to the community.

2 Equity as a special point in information space

Equity has its own symbol in mathematics (=) while equity is also understandable to humans (as any parent who has had to divide up a treat between competing siblings will understand). The *meaning* of equal is the same in both cases.

Equity as a human value is therefore very useful as it becomes a carrier of information between the underlying physics and human functioning; particularly when measurement can be used. In both cases this information transfer occurs in only a very small part of information space (all the other parts are non-equal), but unlike zero, equality can occur anywhere on the continuum.

3 Data variability:

- Faeces and urine variability
    - Faecal weights vary from 60 g/p/d to 400 g/p/d.
    - Diet influences faecal weight with dietary roughage strongly correlated to faecal weight.
    - Nitrogen content of toilet wastes is influenced by protein in diet.
    - Most of the excreted nitrogen is in the urine.
    - Nutrients in an adult’s diet are almost all excreted – in contrast, children retain nutrients as their bodies grow.
    - On a dry weight basis there is as much mass in urine as faeces (arguably more in urine 50 – 70 g/p/d).
    - Vegan faeces degrade faster than carnivore faeces (attributed to oxygen being able to penetrate into the high fibre faeces of vegans).
- Use of water for the toilet flush is technology dependent.
- Greywater variability is influenced by:

- Technology.
- Personal behaviour – washing frequency and length etc.

To address fairness and equity values, this variability needs to be accommodated. Two particularly useful attributes of this variability are:

- Nitrogen is source dependent – 90% is in the urine, 5% in faeces, 5% in greywater.
- Water use can be measured.

3.1 When data meets technology

When this variability in the source data meets a technology, then further useful divisions are:

- Variability in nutrients: consider source-focussed technologies.

Table 1

	Nitrogen	Are technologies available
Urine	90%	Yes – urine separating toilet bowls
Faeces	5%	Yes – composting, evaporation, pit, tanks etc
Grey water	5%	Yes – sewerage

- Variability in water volumes:
  - Technology considerations – water use that is influenced by technology choice:
    - Water reduction fittings.
    - Elimination of toilet flush - 25% of sewage flows.
    - Reuse greywater as toilet flush.
  - Personal behaviour – need to change undesirable behaviour:
    - Measurement (or not) influences the motivation to choose technologies and may influence behaviour such as: frequency and length of shower.

For convenience and simplicity this variability will be dealt with as either: volume or Burden. Where volume = water; and Burden is all those chemicals other than water (which includes organics) and includes the cost of removing them from the water. Sewage is a mixture of water and Burden from three different sources – faeces, urine and greywater. Treatment technologies deal with the Burden – or more particularly reduce the Burden to acceptable discharge concentrations.

3.2 The variability in mathematical form

Sewage is a mixture of three different sources (s): faeces, urine and greywater.

Equation 1

$$Sewage = f(faeces, urine, greywater) = \sum_{s=1}^{s=3}(Source_s)$$

Each of these sources can be further subdivided into its chemical components: water, nutrients, carbon and public health attributes such as pathogens and toxic chemicals.

Equation 2

$$Source_s = f(water_s, nutrients_s, carbon_s, pathogens_s)$$

Rewrite equation 1 for the chemical components of equation 2:

Equation 3

$$Sewage = \sum_{s=1}^{s=3} (Source_s) = \sum_{s=1}^{s=3} f(water_s, nutrients_s, carbon_s, pathogens_s)$$

For the i[th] person (P):

Equation 4

$$Sewage_{P(i)} = \sum_{s=1}^{s=3} (Source_{s(i)}) = \sum_{s=1}^{s=3} f(water_{s(i)}, nutrients_{s(i)}, carbon_{s(i)}, pathogens_{s(i)})$$

3.3 Attaching human values to Equation 4

Fairness and equity are human values while Equation 4 is physics. To enable the information in Equation 4 to influence human decisions there is a need for a social interface with the physics.

In preparation for this task, Equation 4 can be reformulated:

- As water is the dominant component of sewage and water meters are readily available, then volume is a useful measurement to which fairness and equity values can be attached.
- In contrast, nutrients and carbon have very little volume but have considerable treatment requirement (microbial (and chemical/physical) processes). They can be given a single label, *treatment burden* for accommodating fairness and equity values.
- Pathogens are primarily in the faeces and need different considerations from water and nutrients.

The components most useful for fairness and equity considerations are *volume* and *treatment burden,* thus Equation 4 can be formulated for these social purposes as:

Equation 5

$$Sewage_{P(i)} = \sum_{s=1}^{s=3} f(Volume_{s(i)}, Burden_{s(i)})$$

Fairness and equity can be viewed as an optimisation procedure where fairness is a variation from equity that is socially acceptable. It follows that optimisation for human purposes, necessitates a link between Equation 5 and the human domain. The economic system is convenient for this link as commerce manufactures technologies that have both: a measurable performance (this being a measure of the *burden* removed by the technology) and a cost. It follows that a linkage can be formed between Equation 5 and the human domain by dividing the cost of the technology by its measured performance; the measured performance being experimental evidence of Equation 5 in the particular technology. This puts the technology's performance information in a socially useful form:

Equation 6

$$\$/_{Unit} = {}^{Technology\ cost}/_{measured\ performance}$$

Where: Unit ≡ measurement type (g/d or m^3/d) and chemical component (N, BOD_5, TSS, etc).

The measured performance of Equation 6 can be any or all of: nitrogen, BOD_5, TSS, volume etc., enabling the cost efficacy of each type of technology to be quantified: nitrogen ($.d/g(N); BOD_5 ($.d/g(BOD_5); TSS ($.d/g(TSS); volume ($.d/m^3) .

Equation 6 can also be applied to individual system parts to enable comparison of combinations of technologies in which the treatment occurs in different parts of the system (discussed further below). This analysis could be extended 'upstream' for cost comparisons of sedimentation and denitrification technologies, and source separation technologies.

4 Applying fairness and equity values to treating the Burden

Faeces and urine have a high Burden (95% nitrogen and ~50% of BOD_5) contained within only 1% of the volume. It follows that consideration of fairness and equity in treating the Burden must begin with separate consideration of each of the three sources. This is also necessary as some technology types do not require a water-based transport system (and hence do not require a *sewerage system*). Indeed, the purpose of the governing act (Resource Management Act) necessitates consideration of reducing water use, energy use, and nutrient recycle potential as these are the *natural and physical resources* needing to be managed for future generations.

It is fair and reasonable that technologies that use less water, less energy and recycle all nutrients are encouraged. The way our institutions handle (or avoid) these more sustainable technologies is an important part of the question.

4.1 Applying the sustainability zeros

The sustainability zeros (zero water, zero energy and nutrient recycle) attach to mass which is external to any technology, consequently sustainability values need to influence the *initial* approach to technology choice.

Also the notion of **best for a community** contains elements of localness – it is particular to a community, its geographical location and its environment. So if we were to take the *natural and physical resources* listed in the governing Act's purpose then we could sort these *natural and physical resources* according to the local priorities. Thus:

- Water – priority for a community that has water shortages.
- Energy – priority where energy is from non-renewable sources.
- Nutrients – priority if located in the catchment of a eutrophic lake.
- Cost – priority for a low socio-economic community.

Using the community's **priority** *natural and physical resource*, all technologies can be arranged on a best to worst scale according to the amount of this resource used:

Best (technology 1) .... Worst (technology x)

← need mechanisms that move the choices in this direction

For social processes, two things arise from prioritising technologies in this manner:

- Mechanisms for encouraging the **best** technologies are needed, in particular:
    - The **best** technologies must be within scope for the public debate – one cannot choose a technology that is not known about.

- It is fair and reasonable that anyone wanting to choose the **best** technology is not disadvantaged.
- If the **best** technology is not available (or not socially acceptable) then commerce needs to be sent appropriate signals.

Applying sustainability values involves more of the social milieu than is captured in most public debates about these issues.

4.1.1 Applying the sustainability zeros to Glenorchy

By way of example, Glenorchy's environmental issue is claimed to be nitrogen input into Lake Wakatipu. From the nitrogen perspective, the evidence shows that any technology that captures urine will remove 90% of the nitrogen from the waste stream. If this technology captures urine + faeces, then 95% of the nitrogen will be captured. Further, if this technology does not require a water-flush then there will *also* be a 25% reduction in water consumption and a concomitant reduction in energy requirement. Using the data (summarised in Table 1) and Otago Regional Council mechanisms for determining N to receiving waters, then the effects of technology type (where a number of technologies fit within each type e.g. AWTS) can be assessed as to their possibilities for meeting discharge standards (Figure 2). In this case the ORC intended discharge standard is 10 kg (N)/ha/year.

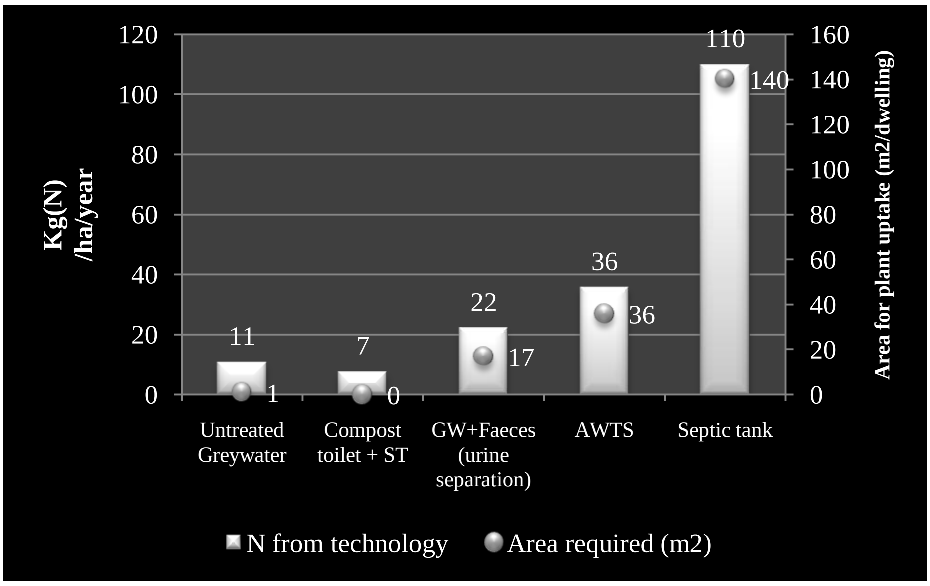

Figure 2 – Nitrogen discharges from different technology types and untreated greywater from a dwelling containing 2.6 people on an 800 m^2 section. The *area required for plant uptake per dwelling* is based on 570 kg(N)/ha/yr plant uptake to remove the residual N (less the 10 kg/ha ORC target) from the technology. Note that the untreated greywater and compost toilet technologies assume zero N discharges from reuse of the source material (faeces & urine).

The clear technology winners that most easily meet discharge standards without needing plant uptake for nitrogen are toilet waste capturing technologies. From the nitrogen perspective, the 'problem' technology in environmental discharges is the water-based toilet flush. Toilet waste capturing technologies have the added advantage that they reduce water consumption with similarly reduced infrastructure costs – a matter that should be given some attention by authorities.

It also becomes apparent that consideration of toilet waste capturing technologies necessitates the analysis beginning at the dwelling scale as:

- A transport system (for toilet wastes) other than water needs to be considered and this consideration begins at the toilet.
- This is where individuals are making technology choices.
- The flush toilet is deeply embedded in our culture and only a few individuals will initially choose alternative technologies.

Fairness and equity values need to attach to this basic organisational unit in addition to the chemical components of volume (H_2O) and Burden if sustainable technologies are not to be disadvantaged.

With the above evidence, there is a serious question as to whether a centralised sewerage system is the best structure for moving towards sustainable technologies in dealing with our three 'wastes'.

5 Applying fairness and equity values to a sewerage system

Considering that the sewage from a dwelling with sustainable toilet technologies will have both: a different Burden and different volumes and that Equation 6 links fairness and equity to the economic system, then the effects of the presence of these technologies on capital and operating costs of the sewerage system needs to be quantified.

Consider a system with three functions:

- Transport
- Treatment
- Re-entry

The above formulation covers the fact that any non-liquid forms would require a non-water based transport system and *Re-entry* includes the path the chemicals take through the great planetary cycles, which include the atmosphere, biosphere and lithosphere as well as the water cycle. From this perspective:

- Toilet waste capturing technologies would need a mechanical form of transport, and could be designed with re-entry entirely via the atmosphere and the biosphere.
- A sewerage system becomes a special case where the transport system is water-based and re-entry is via the water cycle. With a water-based system, its reticulation system ≡ *transport* and disposal field ≡ *Re-entry*, albeit carbon (BOD_5) & nitrogen also have atmospheric re-entry paths.

A community sewerage system can be analysed by summation of its individual's contributions as measured in volume and Burden:

Equation 7

$$Sewage_{group\ (n)} = \sum_{i=1}^{i=n} \left[\sum_{s=1}^{s=3} f\left(Volume_{S(i)}, Burden_{S(i)}\right) \right]$$

But with sustainable technologies some of the Burden may not be in the sewage. The consequences of this is implicit in Equation 7 as one (or more) of the sources (s) from individual (i) may not contribute Burden (or volume) to the sewage. However, Equation 7 can be made conditional to draw attention to this fact:

Equation 8

$$Burden_{total} = Burden_{sewage} + Burden_{other}$$

Alternatively, rewrite Equation 7 to accommodate Equation 8 for individual (m) who chooses sustainable technologies.

Equation 9

$$Sewage_{group\ (n)} = \sum_{i=1}^{i=n-1}\left[\sum_{s=1}^{s=3} f(Volume_{S(i)}, Burden_{S(i)})\right] + \sum_{s=1}^{s=3} f(Volume_{S(m)}, Burden_{S(m)})$$

Within the validity limits of the test data used in Equation 6, then this can be used in Equation 9 to get an estimate of the financial benefit (reduction in capital cost) accruing to an individual making sustainable technology choices (discussed in Section 6 below).

5.1 Subdividing the sewerage system

For the sewerage system, Equation 6 needs to accommodate the possibility that treatment may occur in more than one part of the system and that some parts may not contribute anything to treatment.

From conservation of mass, the *Burden* of Equation 5 can be described for the i^{th} component of the sewage treatment part as:

Equation 10

$$Burden_i = Burden_{in\,(i)} - Burden_{out\,(i)}$$

Where: the $Burden_{in(i+1)}$ of part (i+1) = $Burden_{out(i)}$.

While the costs attributable to part (i) can be determined by its location in the system and the costs associated with the location's function:

Equation 11

$$Cost_{total} = Cost_{Reticulation} + Cost_{Treatment} + Cost_{Disposal}$$

5.1.1 The Burden

In the case of the Glenorchy Sewerage Scheme (GSS) a part of the *Burden* is treated in the disposal field – determined by Equation 10; while the relevant cost is determined by Equation 11 – see Table 2 for application to the GSS treatment station and disposal field.

Table 2 - Equation 6 applied to elements of the treatment station and disposal field of the Glenorchy Sewerage System (GSS). Note: 1/ Plant uptake is more cost effective than container based. 2/ The same capital cost ($) is used in each measurement of BOD_5, TSS, TN and volume as most of the processes occur concurrently and cannot be separated. 3/ Note the lack of evidence to support a cost advantage for a conventional sewerage scheme. [1] Cost of AWTS's vary widely, this calculation is based on maximum design load and a conservative cost.

	GSS_initial Cost=$1.965m V= 230 m^3d^{-1}	GSS_final Cost=$4.3275m V= 520 m^3d^{-1}	Advantex AX-20 Cost=$14000[1] V= 2 m^3d^{-1}	GSS Disposal field Cost=$6/$m^2$ 570 kg(N)/ha/yr V= 6.75 mm d^{-1}
BOD_5 ($.d/g)	51	49	36	
TSS ($.d/g)	46.7	45	34	n/a
TN ($.d/g)	245.5	239	143	105
Volume ($.d/$m^3$)	8543	8322	7000	900

These calculations reveal that, it is more cost effective (in terms of capital cost) to remove nitrogen by plant uptake in the disposal field than in a container-based technology (Table 2).

5.1.2 Volume

With a through-flow sewerage system the same volume:

- Needs to be carried by the *reticulation* system. Volume affects only pipe size in a reticulation system. Volume does not influence pipe length (this is set by the servicing boundary). In addition, over-sizing pipes in anticipation of future growth is fair as this infrastructure is underground and is expensive to change after installation.
- Influences the residence time in the *treatment* station. Reduced volumes are beneficial for treating the Burden.
- Needs to be infiltrated into the soil for the long term within the *disposal* field. Clean water (Burden removed) can be infiltrated at a higher rate than volume with a high burden.

In addition, the volume of each of the sources (faeces, urine and greywater) could influence design strategy:

- Faeces have very low volumes but a very high Burden (0.15 L/p/d or ~55 L/year; but a BOD_5 estimated at 96,000 g/m^3 compared to raw sewage @ 200 g/ m^3), and most of the pathogens. The low volumes mean that storage can be used as a design strategy (particularly useful for pathogens as in the order of 30 days are needed to ensure sufficient reductions).
- Urine volumes are low enough to consider evaporation as a volume reduction strategy.

The three sources do not need to be mixed.

5.2 Interconnecting the different measurements (volume and weight)

A water-based system (sewage) necessitates calculations being done on a flow rate basis as storage of large volumes of water is very expensive and not a possible design strategy. This is in contrast to faeces (and urine) for which annual volumes are low enough to consider storage as a design strategy. The difficulty sewerage systems have in meeting discharge criteria is mostly due to the cost of designing time into system operation. Compare the cost of the 50L container needed to hold a person's faeces for 1 **year,** and/or the 600 L tank that would hold a person's urine for 1 **year** with the evidence in Table 2: volume costs \$8000 *0.2 m^3/p/d = \$1600 /p; BOD_5 (14.4 g/d faeces + 10.3 g/d urine) = 24.7 g/d*\$50 = \$1235/p; nitrogen (primarily in urine) 12.3 g/p/d *\$240 = \$2952/p.

Sewage flow rates are typically based on volume while Burden is weight based. However, because the Burden has a measureable concentration (B_c) in sewage, such as g(N)/m^3, Equation 6 can be translated across types of measurement by using this concentration – albeit with adjustments for the fact that concentrations change across the technology. For example:

Equation 12

$$Volume(\$.d/m^3) = B_c(g.m^{-3}) \times Weight(\$.d.g^{-1})$$

Within limits[1], volumes are convenient to link these different types of measurement as volume is both: easy to measure and there is considerable published data.

[1] These limits arise as any technology's performance measurement is specific to the test's flow rates and Burden concentration (and climate). Change either volumes or concentration too much and the test data becomes invalid and can only be used with suitable caution.

Volume can be related to many useful social organisational forms:

- Individual – 0.2 $m^3.d^{-1}$ (standard fixtures); 0.165 $m^3.d^{-1}$ (water reduction fixtures).
- Dwelling equivalent (volume in 1 day from a dwelling with 2.6 individuals (ORC)) = 0.52 $m^3.d^{-1}.DE^{-1}$ (standard fixtures); 0.43 $m^3.d^{-1}.DE^{-1}$ (water reduction fixtures).
- Commercial premises – see table H4 in AS/NZS 1547:2012
- Community – ∑(dwellings + commerce + public utilities).

6 Application to a single dwelling wishing to make sustainable choices within a community sewerage system.

A dwelling is a convenient administrative unit for councils as it occurs on a legal title (discussed below). A dwelling equivalent is the sewage generated by a standard number (2.6) of people in this dwelling.

For a dwelling (D) with (m) individuals (i) where N is defined as being net of all sources (s), can be either volume or Burden and is assumed to be the same for all the individuals of Equation 9 (the effect of the technology is the consideration in this section), then for component (N) of the waste stream:

Equation 13

$$N_{D(m)} = N_i \times m$$

With sustainable technologies this Burden can be treated either on-site or in the community sewerage system. If α_{onsite} is the proportion of the Burden (or volume) treated on-site then the amount treated by the sewerage system:

Equation 14

$$N_{D(m)sewage} = N_{D(m)} \times (1 - \alpha_{onsite})$$

For a community of (n) individuals generating an average Burden of (N_i) but with dwelling (D) for which only some of the Burden enters the sewage system (as they have sustainable technologies) then Equation 9 can be rewritten using N and that only some ($N_{D(m)sewage}$) of the Burden of dwelling (D) enters the sewage:

Equation 15

$$N_{group\ (n)sewage} = N_{sewage\ (i)} \times (n - m) + N_{D(m)sewage}$$

N can apply to either Burden or volumes, yet functioning of the different components of a sewerage system are dominated by only certain measures (Table 3).

Table 3

	Reticulation	Treatment	Disposal
Burden	Unaffected	BOD_5 & N dominate	Nitrogen for GSS
Volume	Geography dominates pipe length- volume affects pipe size	Impact on residence time.	Maximums (mm/day) apply (depending on system design)

To give dwelling (D) credit for this reduced load on the community system arising from their technology choice, use the costs of Table 2 for the dominant unit of the component of Table 3 for the on-site treatment due to the technology. Or if the dominant unit is not immediately obvious then repeat for as many units as necessary. The capital cost of treating dwelling D's load on-site can be found by:

Equation 16

$$\$_{D(m)onsite} = N_{D(m)} \times \alpha \times \$_N$$

Where: - for the Treatment station: N = BOD_5 & nitrogen.

-Disposal field: N = volume & nitrogen.

-Reticulation: Equation 16 does not apply.

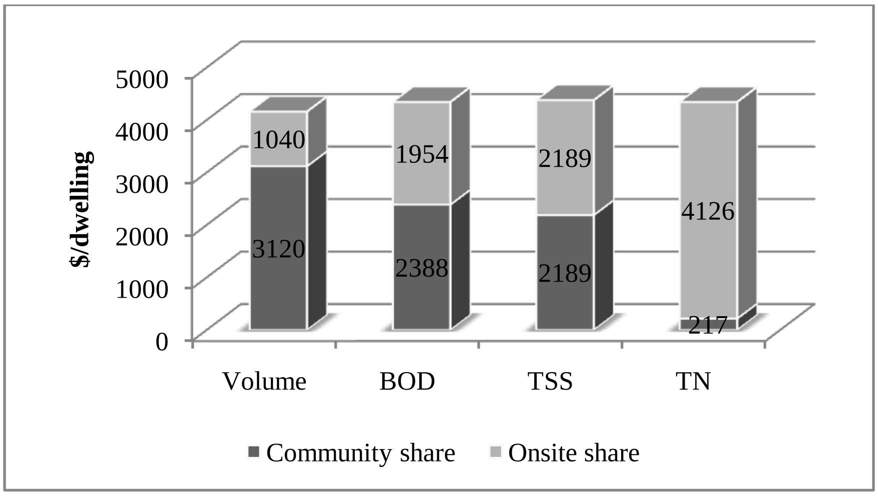

Figure 3 – Using Equation 16 to portion the *treatment station* capital costs for a dwelling that uses faecal waste capturing technologies, but adds its greywater to the sewerage system. Note 75% of the volume is in the greywater but only 5% of the nitrogen. Removal of this nitrogen from the water wastes can be expected to have greater effects on the operating costs due to reduced energy need for oxygenation and reduced need to add carbon (to balance C:N ratio).

Using this method with the proposed costs for the Glenorchy sewerage scheme, the benefit to the community treatment system from dwelling (D's) choice is between \$1954 (BOD_5) and \$4126 (TN). The cost of the community system could be reduced by the value of this on-site share if sufficient residents were to choose the best technology; More likely however, with the need to overdesign any sewerage system means any dwelling choice (however desirable from a sustainability perspective) will have no impact on system design and capital cost.

Yet such individual choices need to be nurtured.

Using averages (as current design strategy use these) and assuming the capital cost remains constant while there needs to be a tangible benefit for a dwelling established by Equation 16, then (for a community of (n) individuals with (m) in each dwelling) the following must be satisfied:

Equation 17

$$\$_{total\ (N)n} = \$_{avg\ (N)D} \times {}^{n}/_{m} - \$_{D(m)onsite} = constant$$

The effect on the average cost for the community from a single dwelling being given credit for sustainable choices can be found by rearranging Equation 17:

Equation 18

$$\$_{avg\,(N)D} = \frac{(\$_{total\,(N)n} + \$_{D(m)onsite})}{(^{n}/_{m})}$$

The dwelling with sustainable technologies would pay $\$_{avg(N)D}$ - $\$_{D(m)onsite}$ for their share of the sewerage system. Using the data in Figure 3 in Equation 18 results in a: \$5 increase for water; \$10 increase for BOD_5; \$21 increase for TN in average costs for a 500 person community with one dwelling choosing toilet waste capturing technologies.

Note that these cost sharing arguments primarily apply to the part of the system dealing with the Burden – that is the treatment station. The disposal field is mostly influenced by the 25% reduction in volumes with a further consideration around nitrogen which necessitates use of a different unit cost (Table 2).

The reticulation system, in contrast, is unaffected by individual choice (other elements of the reticulation system are discussed below).

For fairness and equity considerations all the following must be present:

- Individuals (dwellings) that choose sustainable technologies need credit for the technology(s).
- For the community sewerage system, debate around fairness and equity issues revolve around:
  - The actual relationship between the increase in average cost v's dwelling benefit - Equation 18.
  - The difference in BOD_5 & N benefit needs wider considerations, for which the effect on operating costs can be considered (Figure 3).
  - Consideration that sustainable technologies could prevent the need for future upgrades of the treatment station.
  - Community benefit from reduced water rates (this perspective is not valid if water meters and charging is used).
  - Dwelling (m) may change their technology choice at some time in the future – fairness necessitates rebalance of the benefit (a one-off fee for any increased Burden could be considered).

7 Application to current versus future residents

To apply fairness and equity values to current and future residents use the proposed flow and costs of the GSS (Table 4) in Equation 6 – in effect this is using Equation 6 at the community scale rather than the technology scale. Equation 6 can be applied to both capital and operating costs, however in this case only capital costs are considered.

It becomes apparent (see Figure 4) that the reticulation system is the component that needs additional consideration with respect to sharing the cost fairly and equitably between current and future residents. This arises as pipes need to be sized for ultimate flow and must pass any empty sections if the whole town is being reticulated at once.

Table 4 – Flow rates and costs for the proposed Glenorchy Sewerage System (GSS). Note: Preliminary and general, traffic control, miscellaneous and GST not included in these figures.

	V(m3/d)	Reticulation ($m)	Treatment ($m)	Disposal ($m)
GSS_Initial	V=260	$2.406m	$2.205m	$0.240m
GSS_Final	V=520	$2.748m	$4.3275m	$0.480m

However the whole town does not need to be done at the same time. Partial reticulation is a possible tool to share the costs more equitably between current and future residents, particularly as future subdivisions are located in identifiable parts of town. Installing the sewer to these locations can be carried out when the subdivision is proposed, and the costs shared between the developer and current residents on the street (who have on-site disposal at present) at the time of subdivision.

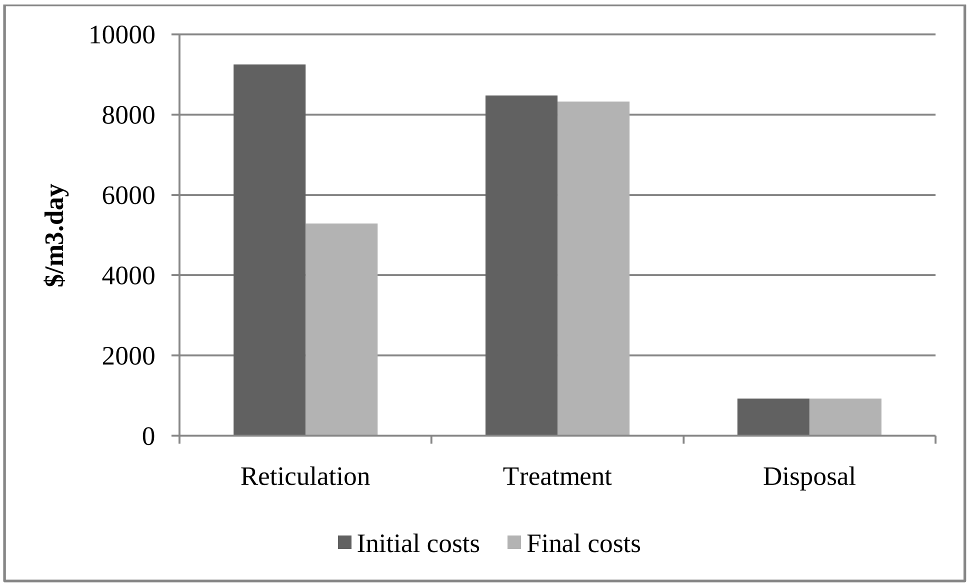

Figure 4 – Capital costs for the GSS proportioned by system components and initial and final costs. The initial and final costs are a good indicator of the financial burden to be shared by current and future residents.

It is also apparent that for treatment and disposal a 'standard' charge based on volume and system components (such as: $8500 per m^3 for treatment, $1000 per m^3 for disposal) is a possible alternative funding mechanism. Particularly as fairness and equity values attach to volumes and volume is only generated by current residents (and visitors).

This is in contrast to the reticulation system which necessitates consideration of future peak flows to size the pipes adequately for these anticipated flows.

8 DE as a useful human interface for fairness and equity values

For administrative purposes, a dwelling equivalent (DE) is a convenient measure as it occurs on a legal title, which is an administrative unit used by councils. This links costs, performance and volumes to the law that councils administer. DE is however, based on a 'standard' occupancy of a dwelling (both # of people and days of the year). This standardisation is convenient for design (and administration) purposes, but can negate some of the source variability identified above.

To determine a cost per DE, multiply the DE volume (which may be calculated from concentrations by Equation 12) with the cost per unit volume (Table 2):

Equation 19

$$\$_{DE} = Cost(\$.d.m^{-3}) \times Volume(m^{3}.d^{-1}.DE^{-1})$$

Where: Volume per DE is determined by Equation 13.

Commerce can also be related to legal title (and hence DE) by volume proportion (using either published data or actual measurements):

Equation 20

$$\$_{commerce} = \$_{DE} \times \frac{V_{commerce}}{V_{DE}}$$

When DE use only standard volumes, equitable occurs when the capital (and operating) costs of the system are shared equally according to Equation 19 with adjustments using Equation 20 for non-standard volumes. Equation 20 may also be used for the dwelling that does not have a flush toilet as there will be a 25% reduction in sewage flow rates from a standard DE (these more sustainable technologies are discussed further below); not a full reflection of their reduced contribution as the toilet contributes ~50% of BOD_5 and 95% of the nitrogen.

However, these variations from 'standard' are a good place to attach mechanisms for managing fairness and equity values.

Water meters on the input side of a building enable both: charging for water use (and a rough measure of occupancy); and an estimate of sewage outflows. Water meters give visibility to source variability with different dwellings (and commerce etc), negating to a degree the need to use DE. Albeit water meters on the input side means those who irrigate gardens and lawns may pay disproportionately more for their sewage. But this gives them an incentive to use their greywater for these tasks, which further reduces the Burden on the treatment station.

In contrast to equitable, fairness includes the need to be socially and administratively efficient. Social efficiency can include for example a family being charged a lesser rate for their Burden and/or volume. However, there is a level of variability for which the cost of collecting the data exceeds the benefit.

9 Is communal reticulation the best system?

Considering that:

- Sustainability for our waste streams necessitates a challenge to the incumbent flush toilet.
- Sewer's cost is unfairly loaded on current residents (Figure 4).
- Social signals to choose more sustainable technologies are obscured by sewers.
- Mechanisms of social change point to the importance of only a few individuals.
- Peak phosphorus is due in 2025 and a significant portion of total phosphorus is used to grow our food and consequently appears in faeces and urine.

- Population increases are getting beyond the ability of the world to feed.
- Water shortage is becoming a politically destabilising issue.

Then there are some sewerage-specific attributes that can be considered:

- Conventional sewers carry solids and have poor earthquake resilience as they are dependent on steady gradients for moving these solids along the sewers – else they block.
- Treatment systems do not show a strong scaling effect (Table 2). Upgrades can be done in increments.
- There is no implicit requirement for a centralised end-of-pipe treatment station – treatment can occur in any part of the system; which can include an on-site system at each dwelling.
- Conventional sewers lock in end-of-pipe treatment stations and need minimum flows.

Considering also that sustainability values necessitate consideration of those technologies that use no water, need no energy and recycle all nutrients.

Given that sewers are sub-optimum from so many angles, but are favoured by councils for a myriad of reasons not necessarily related to the evidence – in part leading to path dependency. Then the role of the primary adopter within a conventional sewerage system needs to be raised to the top of the list of needed improvements to the system.

Given also the lack of evidence of an advantage for end-of-pipe solutions for treatment station perhaps it is time to:

- Allocate responsibility for primary treatment to the land owner.
- Institute management mechanisms to ensure adequate functioning of on-site systems.
- Develop information mechanisms encouraging reduced water use, reduced energy use and nutrient recycle.
- Link these information mechanisms to the dwelling; as a dwelling is a significant decision maker that is also an economic actor in modern society.

10 Creative aspects of this variability

It has been argued above that fairness and equity values attach to three different physical/chemical aspects of the complexity, all of which need a place in any social mechanism that may claim to be fair and equitable:

- Volume (the *water* component of each of the three wastes).
- Burden (the other chemical components of the three wastes).
- Dwelling scale.

To accommodate this variability in a fair and equitable manner that also encourages the development of more sustainable technologies, it is convenient to consider this variability using three disciplines: administration, measurement, information.

The lowest administration cost that is consistent with reliable measurement, yet retains the information in an effective form is the 'best' framework for accommodating this variability while accommodating this variability.

- *Administration* – costs need to be minimised:
    - Lowest cost would be a mechanism that self-organised and didn't require any administration – but these are not yet within human grasp, albeit the above analysis contains pointers as how the self-organisation may be possible.
    - Non-measurement based mechanisms such as using a technology-based performance range eliminates the need for regular measurement. For example, administration only needs to know that toilet waste capturing technologies are present (and there are no flush toilets) for the water-based discharge levels (see Figure 2) to be known to within acceptable discharge levels.
    - Computer based administration (such as: if sust-tech is present charge X else charge Y) have very low running costs – albeit the initial programming may be a significant one-off cost necessitating staff time. Note also telemetry possibilities that could automate data processing.
- *Measurement* - available technologies and how these measurements interact with administration:
    - Location of water meters at the dwelling enables technology choices to affect the rates bill. This is where measurement interacts with information flows and decision making.
        - Accessing the data (telemetry is possible and computer is not costly).
    - Measurement of chemical (nutrient) and pollutant load (BOD_5, TSS etc).
        - Sensors are currently confined to laboratory and technician use.
        - However these measurements will occur within a range of values – this range of values has administrative value. For example, greywater values of N will occur within a range that falls within acceptable discharge limits – regular measurement is not necessary to confirm this (see Figure 2 above). Administration can use this data within its confidence limits as an alternative to regular measurement.
- *Information* – the form of this information is important for the 'trajectory' of any society:
    - Information generation.
        - This information needs to be gathered in a manner that includes the 'best' technology, for example:
            - All the measurements of sewage (which is a mixture of 3 different sources) are an average of these 3 sources. The underlying variability is present but not visible in this average.
            - As a consequence, the data that leads to the benefit of toilet waste capturing technologies (Figure 2) is not sufficiently visible in these sewage measurements to trigger technology development. This visibility is needed to avoid the 'tyranny of the average' and 'path dependency'.
    - Information transfer.
        - *To commerce*: particularly if there is a need to stimulate technology development.
            - The information's use may contain some explicit minimum scale as any technology will need to serve the full range of *individual* variability that exists in any population (arising from factors such as diet). Many different people will use the same toilet design and it must work for them all.

        - Commerce sells ‘units’ with toilet pan being the minimum scale.
    - *To residents*: Incentives to choose more sustainable technologies (these offer different mechanisms to the exercise of law and are potentially far less combative).

The *best* mechanism will accommodate all of the above with possible prioritisation arising from identification of the most serious constraint. The author’s experience would suggest that information transfer to residents, particularly incentives to choose sustainable technologies is a priority in Glenorchy.

11 Mechanisms

The mechanism’s task is to move the community towards the ‘best’ technology as prioritised by the community’s most limiting *natural and physical resource* (Section 4.1). To do this, any effective mechanism will need links to three attributes of human functioning on our planet:

- Underlying chemistry/physics (our planet) – identifies the ‘best’.
- Social processes – needed for moving towards the ‘best’ technology choice.
- Information transfer – the ‘oil’ that drives the system.

In terms of the underlying chemistry, the ‘best’ technology must consider the evidence for the influence of technology on nitrogen loads to receiving waters in Section 4.1.1 above, that points to toilet waste capturing technologies as being the best for keeping nitrogen from receiving waters. Indeed one could apply a similar analysis to all the *natural and physical resources* of the governing Act (water, energy and nutrients being the main ones for our waste) and the same result would arise. The type of toilet waste capturing technology is therefore an important constraint needing resolution and must be intrinsic in any mechanism that claims to be sustainable.

For the social processes attribute, fairness and equity values are a very useful moderator as they have such strong links to human functioning, yet can be easily quantified via volume and Burden (Section 3.3).

However, with a priority on toilet waste capturing technologies, the focus for any mechanism moves to the dwelling scale; as a transport system from the toilet other than water must be considered. Beyond the toilet, greywater is mixed with toilet wastes and this excludes any technology that deals with their distinctive characteristics. The dwelling needs to be the **analytical boundary** for any mechanism claiming to be sustainable.

However, in terms of information flows the dwelling is a very good focal point for a number of reasons:

- Occurs on a legal title which is a council’s operating unit.
- Decision making point in social organisation.
    - A primary adopter (change agent) would find it easier to make decisions about technologies that only affect a dwelling.
    - Water saving technologies are dwelling scale.
    - Source variability (particularly the high Burden low volume of toilet wastes) is (or could be) visible.
    - Water meters are a measuring technology that is available.

- A family is a significant economic actor to which information signals can be sent via the economic system (penalty and rewards). A direct technology linkage may not apply in the case of rental properties, but the dwelling owner is likely to be equally responsive to these economic signals.
- A dwelling (or more particularly the individuals that live in the dwelling), being the source of the 3 waste streams, means the energy budget datum can be defined (relative to the toilet seat in the case of faecal wastes).
- Extendable to commerce (and public utilities) by volume proportion.

With a focus on the dwelling, and it being given every encouragement to choose sustainable technologies then commerce's highly sensitive antennae would pick up this information and effect a technology change. The profit motive is likely to be sufficient incentive.

It follows that to be effective any mechanism needs only three components:

- Use of the dwelling as an analysis unit – extendable to commerce by volume proportion.
- Costs (capital & operating) based on volume data from water meters at each dwelling (legal title in the case of commerce and public utilities).
- Means of linking the dwelling's volume and/or Burden to the economic system via the rates bill.

The mechanism's efficacy becomes embedded in its structure (the dwelling analytical unit); its links to volumes from the water meters (and possibly Burden if these are also linked); and information transfer to decision makers (a personal decision has an effect on the rates bill). Such mechanisms are less likely to need legal coercion to effect a decreasing environmental footprint.

When applying a mechanism that contains these attributes to a communal sewerage system, then **equity** is that point where capital and operating costs are the *same per unit volume*; albeit the treatment station cost would be more equitable if the Burden were used.

In defining equity in this manner, then a high quality public debate could be framed around **fairness** considerations as an *acceptable degree of variation from equity*. The linkage to volumes carries objectivity into the debate while fairness is a social concept that all can relate to. **Fairness** includes the possibility of giving credit for choosing sustainable technologies (particularly for on-site treatment of the Burden – Section 6).

12 Conclusion

If fairness and equity values are attached to volume (primarily influenced by water) and Burden (all the chemicals other than water) then this forces consideration of each of the three sources that contribute to sewage (urine, faeces and greywater). With consideration of the three sources, the technology we choose for our toilet wastes becomes a prime question that needs resolution before fairness and equity considerations can be adequately dealt with.

From the human-sustainability-on-our-planet for Glenorchy context, sewerage (more particularly, mixing the toilet waste with the greywater) can be shown to be the least effective technology for dealing with nitrogen in the waste stream. However, given the history of sewerage and the legal framework within which councils operate, there is a deeply embedded bias for community based sewerage systems, necessitating the use of water as a transfer mechanism.

Within this human-sustainability-on-our-planet framework, **equity** is a fixed point in information space where conservation of mass (chemistry) meets thermodynamic laws and these interact with the human economic system via our technologies. In effect, the sustainability minimums attach to the quantification that is implicit in the measured performance of these technologies.

For the particular technology that is a community sewerage scheme, equity is satisfied when the capital and operating costs are the **same** per unit ‘pollutant’ (with separate considerations for volume and Burden). That is, when any *difference* in volume, BOD_5 or nutrients results in different capital and operating costs and these can be attributed to the source (such as a dwelling or commerce).

Fairness implies:

- Polluter pays and non-polluters get rewarded.
- The possibility that a socially acceptable variation from this equity can be negotiated.
- Administration costs are a minimum – there is a lower level of variability at which instrumentation limits mean acknowledging the variability becomes too costly.

However, when sustainable technologies occur within a conventional sewerage system then an additional consideration is needed as the sewerage system is a ‘public good’ while the most sustainable technologies don’t need a water-based transport system and can both: occur separate from, yet reduce the load on, the sewerage system.

Resolution of this necessitates consideration of the dwelling scale as a minimum for any analysis that claims to be fair and equitable. The dwelling scale separates the public from the private and coincides with a major decision making unit of social organisation. The dwelling is also a convenient economic actor to which economic signals can be sent to facilitate movement towards more sustainable technologies.

This framework is found to give useful insights when applied to three areas:

- A single dwelling wishing to make sustainable choices within a community sewerage system.
- Sharing the costs between current and future residents (for which one component of future residents is the developers who prepare the land for future residents).
- Fairly sharing the costs arising from the different volumes and Burdens of commerce and public utilities from a dwelling.

Finally a case for building mechanisms for stimulating creativity (in terms of technology development) for the long-term betterment of society is discussed.