Composting toilets in New Zealand:
A scoping study

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EXECUTIVE SUMMARY

Composting toilets have become more common and widespread throughout New Zealand as an alternative to traditional wastewater management in rural and urban settings. There has been a shift in the use of composting toilets, from one of an emergency measure and in remote settings, to a more common practice in rural and urban settings. There are a range of reasons for the increase in uptake of composting toilets which may include financial, ideological, ethical, and environmental motives. Composting toilets can now be found in conventional urban or rural dwellings alongside tiny homes, mobile homes/campervans, holiday homes, cafes/restaurants, boats, camping grounds, backcountry huts and walkways.

This report provides a scoping study of composting toilets in New Zealand to identify the types of systems and the public health issues associated with their operation, maintenance, and waste disposal. The report is informed by a literature review using peer reviewed articles and grey literature and a sample of key viewpoints from various local authorities and public health specialists throughout New Zealand. Information on associated waste(water) practices, such as greywater are outside the scope of this report.

The insights from the literature highlight that there is limited peer-reviewed New Zealand research available with regards to the health risks associated with composting toilets in terms of their operation and maintenance alongside the discharge of the waste product to the environment. The available literature states that consistent and appropriate user operation and maintenance of a composting toilet system is vital to achieve optimal biophysical composting conditions:

- aeration
- moisture content of 50 – 60%
- temperature 40 - 65°C
- carbon to nitrogen ratio of 25/35
- pH 5.5 – 8.0
- porosity 35 – 50%

The international literature states that for a household composting toilet system storage of waste (the maturation phase) should be more than 1 year above 20°C and up to 2 years temperature 2-20°C. The literature also states that the risk to public health from composting toilets is from ingestion of pathogenic organisms and chemicals. Healthy human faeces should have low pathogenic and chemical compounds, but the risk lies with sick individuals contributing pathogen loading to the compost and the personal use of pharmaceuticals (e.g. antibiotics) and hormones (e.g. estrogenic compounds).

There is a joint Australian New Zealand Standard (AS/NZS 1546.2:2008) relating to waterless composting toilets that provides guidance on the operation, maintenance of composting toilets as well as the standards to be met for the end product. The Standard undertakes to provide:

- a set of performance statements that set out the requirements for domestic waterless composting toilets,
- performance evaluation tests to act as a base against which any waterless composting toilet (domestic) can be assessed,

- manufacturers of waterless composting toilets with test requirements to confirm the conditions required to enable the toilet to function satisfactorily and,
- to ensure that a waterless composting toilet is operating and maintained in a safe manner, meeting the health requirements for the removal of composted or partially composted material.

An online survey represented a small cross-section of perspectives from 19 individuals from Regional Councils, District and Unitary Councils, a Government Department, Public Health Units, District Health Boards, and industry consultants. The focus of the survey was to identify public health issues and risks associated with composting toilets but also to contribute to the understanding of the consenting and compliance environment, composting toilet operation and maintenance, and the discharge of the waste to the environment. The survey also identified if any of these issues were resolved.

The survey responses highlighted that within New Zealand there is not a consistent approach to composting toilet consenting with no clear pathway for compliance with national standards. The surveyed respondents stated that some councils require composting toilet users to apply for a discharge consent while other councils view the application of composted human waste to land as a permitted activity. Most survey respondents stressed that the optimal performance of composting toilets and the end product quality is highly dependent on user operation and maintenance. In terms of the discharge of the composting toilet waste to the environment, many survey respondents stated that there was not adequate information available in the New Zealand context about when composted human waste can be discharged to the environment in a way that does not impact negatively on human or environmental health.

The report highlights that composting toilet systems are being increasingly utilised within New Zealand in the absence of a consistent approach to the management of human health risks.

1. INTRODUCTION

1.1 PURPOSE AND SCOPE

This report scopes the current policy, legislation and health issues associated with composting toilets in New Zealand. The report uses insights from selected New Zealand and international literature and from a New Zealand survey. The focus of the survey is to canvas a selection of key regulatory stakeholders to determine the use of composting toilets in New Zealand and, the range of health-related issues associated with composting toilets.

The report does not include on-site domestic wastewater management, practices or standards but only addresses dry systems. For a complete picture of on-site domestic waste management, consideration needs to be made for wastewater management in addition to composting toilets.

1.2 BACKGROUND

In the past decade composting toilets have become an increasingly utilised alternative to conventional wastewater disposal. Composting toilets are now not only found in isolated unreticulated locations, but they are found in towns and cities where wastewater is reticulated. Composting toilets are being installed in tiny homes[1] as well as conventional homes, boats, cafes, restaurants, camping grounds, campervans/mobile homes, holiday homes, backcountry huts and walkways, and utilised during disaster situations such as the Christchurch and Kaikōura earthquakes (ESR 2007). There are a variety of reasons for an increased uptake in composting toilets in New Zealand which include ideological, ethical, financial, and environmental reasons alongside necessity during emergency situations.

Currently in New Zealand, the Australian/New Zealand Standard On-Site domestic wastewater treatment units Part 2: Waterless composting toilets (AS/NZS 1546.2:2008) sets out the approach to composting toilet design, operation, and maintenance alongside waste disposal guidelines. The Standard covers waterless composting toilets for stand-alone units for residential use but, there is an acknowledgement that they may be suitable for non-residential applications. The Standard aims to provide a set of performance statements that form the basis against which a waterless composting toilet may be assessed. There are guidelines for manufacturers for performance evaluations to ensure that the composting toilet will function under the conditions in which it is placed. There is a section within the standard that sets out the operation and maintenance requirements to ensure basic health requirements are met. What is missing in the Standard is guidance for design of waterless composting toilets. It is noted within the Standard that it should be read alongside AS/NZ 1547:2012 On-site domestic wastewater management for treatment of waste liquid. AS/NZS 1546.2:2008 has information on design parameters for domestic and non-residential installations, approach and methods but, no clear guidance for design considerations.

Our scoping study is based on two sources of information, literature, and survey responses. A review the literature focused on composting toilets in domestic, public utilities, business, and recreational situations. Web-based searches between 1986 and 2022 were completed using the following search engines: ScienceDirect, Web of Science, PubMed, ProQuest

[1] According to the Ministry for Business and Innovation (MBIE) a tiny home can be considered a building or a vehicle or a building and a vehicle. A tiny home is occupied by people on a permanent or long-term basis and does not exceed 10m^2 (MBIE, 2021)

Public Health and Google Scholar. The following keywords were used to collate the sources of information for the literature review:

Composting toilet	Composting toilet performance
Compost toilet	Composting toilet operation
Dry sanitation	Composting toilet maintenance
Ecological sanitation systems	Human excreta compost
Ecological toilets	Human effluent compost
Waterless toilets	Human faeces compost
Composting toilet and waste disposal	Chemical contaminants and compost toilets
Health risk and compost toilets	Microbial assessment and compost toilets
Pathogen assessment and human excreta compost	

An online survey was sent to approximately 60 individuals and focused on those with direct involvement with territorial regulation of wastewater, discharges to the environment and the protection of public health.

1.3 REPORT FORMAT

Section 2 reviews selected literature on issues associated with composting toilets within a New Zealand and international context. Section 3 describes the key perspectives from the survey, followed by Section 4 which provides a discussion of the key findings.

2. INSIGHTS FROM THE LITERATURE

Peer-reviewed articles and grey literature have been selected for relevance to composting toilets within a New Zealand context. International literature has also been included and has resulted in a breadth of composting toilet literature which incorporates urban, rural, and isolated settings. The following sections define composting toilets, the public health risks and the standards and regulations used to reduce the risk. Following this is a description of the key findings on historical and contemporary Māori values with concern to human waste and compost.

2.1 COMPOSTING TOILETS

1.2.1 Definitions and general requirements

Composting toilets are defined as a well-managed and ventilated container or unit that provides optimal temperature and moisture conditions for the biological and physical decomposition of human faeces into compost (USEPA 1999). The compost can be subsequently applied to the environment typically as a soil enhancer (Anand and Apul 2014). According to Standards New Zealand, waterless composting toilets are defined as a device that collects human excreta, domestic organic matter, and bulking agents to produce a product using aerobic stabilisation and natural disinfection processes that over time is not considered a risk to public health (AS/NZS 2008). This description is compatible with international definitions (Balzer 2012).

In an international context composting toilets are often referred to as waterless or dry toilets and are one of the five improved sanitation options identified by the United Nations Sustainable Development Goals (UN 2015).

Composting toilets employ a relatively simple technology and decomposition principals but rely on a high level of user interaction and knowledge to appropriately manage the decomposition process to create a finished compost product which is no longer a risk to people and the environment (Anand and Apul 2014). The process itself is aerobic thermophilic digestion where elevated temperatures (40-65˚C), along with balanced correct ratio of carbon and nitrogen sources, decompose the waste material into a useable nutrient rich product. It is widely agreed (Aburto-Medina et al 2020) that the optimum conditions for composting human waste effectively include the following biophysical conditions:

- aeration
- moisture content of 50 – 60%
- temperature 40 - 65°C
- carbon to nitrogen ratio of 25/35
- pH 5.5 – 8.0
- porosity 35 – 50%

For effective management of a human waste compost system, that minimises public health risks, the system must be operated and managed to ensure that the system:

- is fit for purpose for the users (i.e. chamber size) and environmental conditions
- requires minimal handling

- minimises or eliminates any liquid, including urine, from entering the composting system
- allows an adequate decomposition time
- appropriate release of compost to the environment.

The requirements in New Zealand may differ to international requirements and are discussed in Section 2.4. As AS/NZS 546.2:2008 requires no contact between the composting material and people, systems are not manually aerated. Along with difficulty maintaining thermophilic temperatures this may lead to pockets of poorly composted material and therefore the composted product should be treated as hazardous until it has been buried for 6-12 months.

1.2.2 Composting toilet types

There are two main types of waterless composting toilets: continuous composting toilets and batch composting toilets, which are discussed in the sections below. Within both types, there are many models available ranging from off-the shelf units to self-built designs. Designs can be completely off grid and manually managed or automated systems that require little manual handling.

Continuous composting toilets

As Figure 1 illustrates, continuous composting toilets are single chamber systems where the space under the pedestal receives waste until composting is completed or the system is full (BRANZ 2007). Organic bulking agents, such as sawdust, are added to aid the decomposition process. Critical for reducing odours from this system is an air inlet and exhaust which may be driven by convection, electric or solar powered fan (BRANZ 2007). This composting system minimises the handling of the human effluent which is an advantage to minimise risks to public health. Issues may arise, however, with the ability of the composting unit to reach the thermophilic conditions required for decomposition. The continuous composting toilets need to be protected from disease vectors such as flies, vermin and birds while also ensuring adequate ventilation to aid the decomposition process.

Batch composting toilets

Batch composting toilets (Figure 2) include a container or bucket that, when full, is moved outside to a protected location to allow the contents to decompose and is replaced by an empty container or bucket (BRANZ 2007). The advantages of this system are that the human excreta can be left to mature and decompose without continuous addition of new potentially contaminated faecal material. Disadvantages include a higher level of user interaction and handling due to the small size of the system, that requires frequent changing of the container or bucket. In addition, the domestic dwelling needs to be located on a sufficient section size to limit the contact of humans and animals with the decomposing human waste. Like continuous composting toilets, batch compost containers also need to be protected from disease vectors such as flies, vermin and birds while also ensuring adequate ventilation to aid the decomposition process.

Both of these systems may be further categorized by whether they separate urine at the collection point or not (Anand and Apul 2014; Ersson and King 2019).

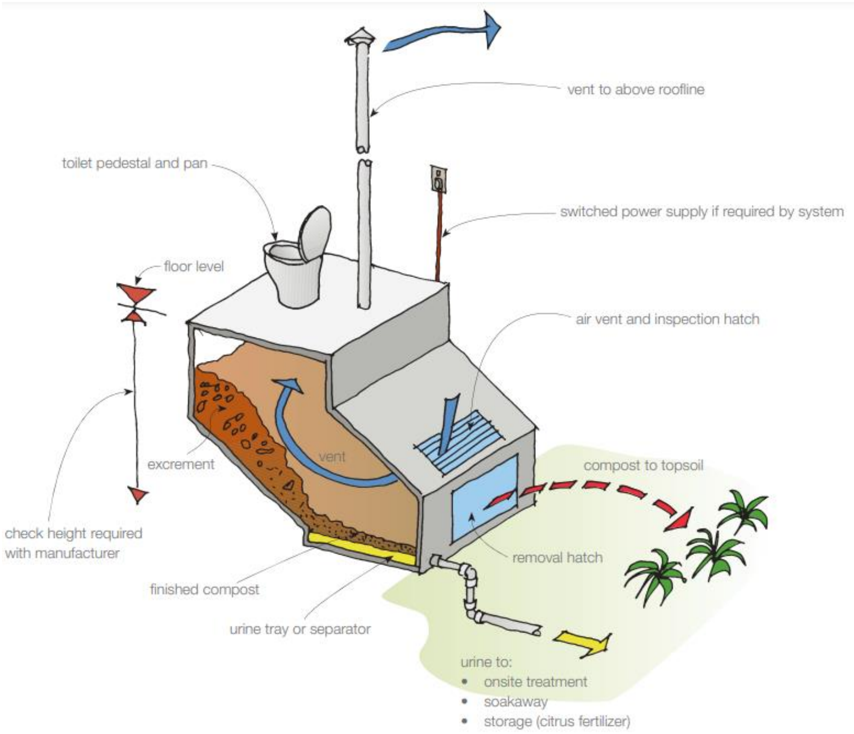

Figure 1 Continuous composting toilet, taken from BRANZ, 2007

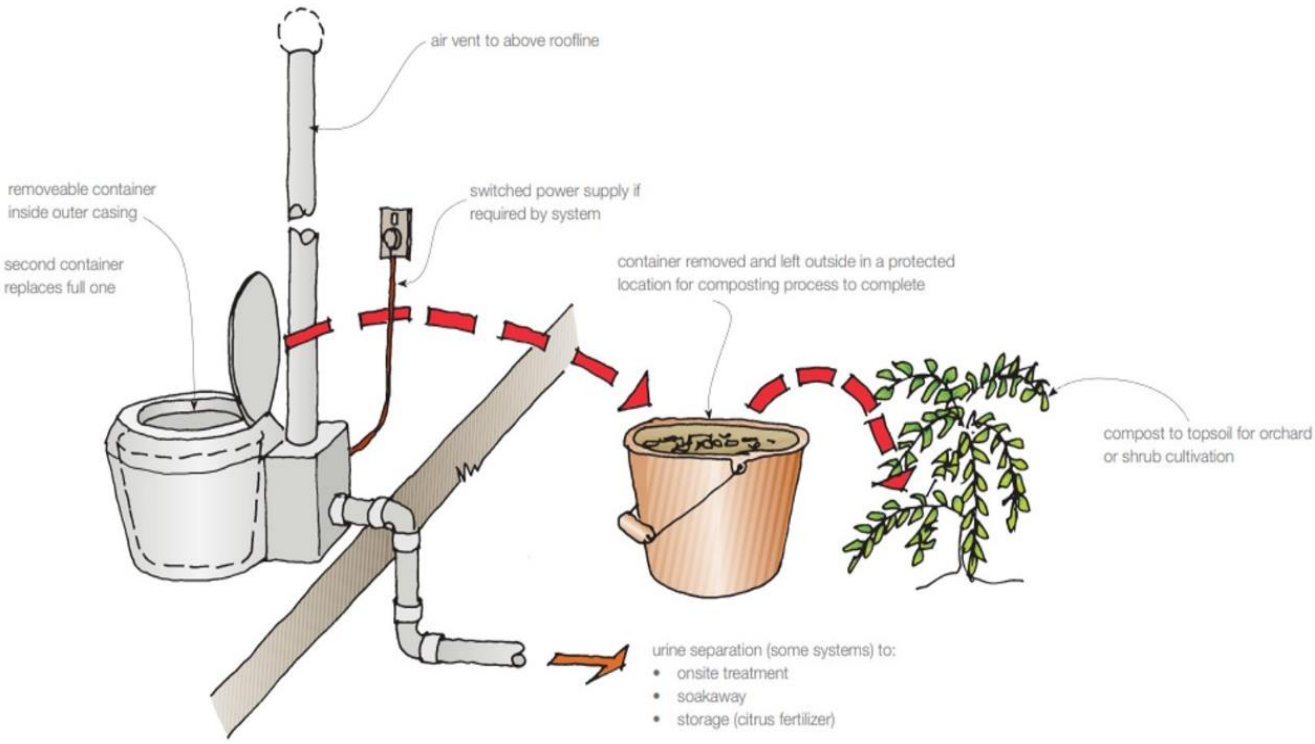

Figure 2 Batch composting toilet, taken from BRANZ, 2007

Composting toilets without urine diversion

In this type of toilet system, urine and faeces are collected in a same chamber. Liquid accumulation at the bottom of the vault which must be drained off, is one of the constraints in this type of toilet. To avoid anaerobic conditions developing designs usually ensure a drainage layer, a sieve-tray or a slope, so surplus liquids can be drained, stored, and removed to a storage tank for further treatment. Some designs evaporate the leachate by electrical or solar heated devices. Leachate should be handled with care, as it may contain pathogens and its handling, treatment and management must be considered thoroughly in the planning stage. Berger (2010) propose dilution of leachate 1:10 with water and application to non-food plants, but this would be likely to require a resource consent in New Zealand. In the absence of guidelines in New Zealand there is a potential risk to public health from accidental ingestion through handling or contact with the soil or plant. In Australia, significant guidance is provided by most States how to minimise the public health risk from manual bucketing of greywater.

Urine separation composting toilets

In these systems, the two different excreta wastes are treated separately. As long as the users are healthy, urine does not normally contain any pathogenic organisms. Urine is high in nutrients, which makes it a very useful fertiliser. Separating the urine has the advantage of reducing the odours and excess liquid in the composting pile. Faeces, which are high in pathogens and have a medium to low nutrient value, are dealt with separately. Urine only needs to be held in an enclosed container for a period of time (6 months), or if a user is unwell the pH can be allowed to increase to destroy any pathogens that might be present. For dry systems, faeces are composted, and a useful soil conditioner is produced (Aburto-Medina et al 2020; Green and Ho 2005). AS/NZS 1546.2 requires burial of the composted faecal material after 6-12 months at a depth of soil greater than 100 mm to minimise the risk from pathogens before use as a soil conditioner.

Pathogen removal

In summary, some of the primary design and operational parameters that influence pathogen inactivation in composting toilets are:

- appropriate chamber size for adequate storage time given the number of users and expected temperature and moisture content in the pile of excrement
- designs or inclusion of materials that increase temperature and decrease moisture content
- diversion of urine from the faeces
- type and amount of dry bulking material (i.e., desiccant) added that influences the porosity, moisture content, pH, and C/N ratio of the excreta
- presence or addition of free ammonia (Naughton et al 2019).

1.2.3 Operation and maintenance requirements

Manufacturers compliance requirements are set out in AS/NZS 1546.2:2008, Appendix F. Within these requirements, manufacturers must undertake batch release tests where one or more units are tested according to NZS ISO/IEC 17025 (Standards NZ, 2018). There are specific requirements to be met for performance to ensure protection of public health and environment. These requirements cover; the end product quality (Appendix A, AS/NZS 1546.2); assessment of watertightness of the toilet system (Appendix B, AS/NZS 1546.2); performance evaluation process (Appendix D, AS/NZS 1546.2); design factors, whether the system is for residential or non-residential use, design capacity, and the specific conditions for composting (Appendix E, AS/NZS 1546.2).

Waterless toilets require regular attention, such as raking, emptying and pest management. To prevent odour in a composting toilet, anaerobic decomposition should be avoided. The addition of bulking material and regular mixing can prevent the onset of anaerobic conditions (Mehl et al 2011, Chapman 1993), along with periodic addition of a desiccant. It is noted that AS/NZS 1546.2:2008 specifies that there should be no contact between a person and a compost pile that has not completed the composting process. Careful maintenance of the toilet by the owner, including effective use of bulking material, as well as the efficient functioning of the pit ventilation systems installed allows efficient composting to occur (Tanner et al 2021). That said, the composting process is quite a complex process with certain factors that can affect the efficacy of the process. This is especially the case with a more manual system such as the batch system where manual maintenance and operation is required.

Factors affecting composting process are outlined below.

Aeration

Organic compounds present in the waste are oxidized under aerobic conditions and microorganisms produce carbon dioxide, ammonia, volatile compounds and water as end products. Insufficient oxygen levels lead to anaerobic conditions, culminating in odour issues and incomplete composting. However, too much air flow can lead to heat loss, another important factor in the composting process. Optimal oxygen concentration has been suggested as between 15 and 20% (Miller 1992).

Moisture content

The moisture content in the compost pile needs to be managed in order to maintain aerobic conditions. There is a balance required between enough moisture and too much. Too little moisture (less than 40%) can inhibit decomposition by reducing microbial activity. The amount of moisture required is debated, but many studies have shown that the optimal moisture level is between 50 and 60% (Depledge 1997).

Temperature

The composting process comprises different phases, each categorised by a different temperature. Initially, the degradable material is decomposed by mesophilic microorganisms (19-45˚C). This process, leads to heat production, increasing the compost temperature above 45˚C. The elevation in temperature enables thermophilic microorganisms to activate (Funamizu and Zavala 2016). This thermophilic phase enables degradation of organic matter and destruction of pathogenic organisms at temperatures between 50 and 65˚C. Above 65˚C a reduction in thermophilic microorganism activity occurs (Depledge 1997). This process occurs towards the end of the composting process and leads to the maturation phase, where the temperature reduces to mesophilic range (19-45˚C) where mesophilic microorganisms continue to decompose the remaining organic matter.

Management of the process is required to achieve the varying temperature steps required for composting. Dependent on the climatic conditions, insulation of the composting pile is required. In addition to insulation, mixing of the compost has been shown to elevate temperatures to the required range.

Ratio of carbon to nitrogen

The ratio of carbon to nitrogen (C:N) required for composting is between 25 to 35. Human faeces are normally deficient in carbon, with a typical C:N ratio of 8. To facilitate composting, an additional carbon source is required (Depledge 1997). Various carbon bulking agents have been demonstrated as suitable for composting, such as wood shavings, grass and leaves, sawdust, toilet paper and straw (Depledge 1997). Insufficient carbon addition results in odour issues, which is easily managed by addition of more carbon bulking agent to the compost.

pH

The optimal pH range for aerobic decomposition of organic matter by composting is 7.5–8.5. However, a pH of > 9 is required for removal of most pathogenic bacteria and viruses. Helminth ova also require high temperature to effectively inactivate the ova, (Mehl et al 2011), but helminth ova are not a human health issue in New Zealand. Aerobic decomposition of organic matter is hindered at pH levels greater than 9, presenting a conflict between the breakdown of organic matter and the removal of specific pathogens by increased pH. Extended thermophilic treatment and burial is specified in AS/NZS 1546.2: 2008.

Duration

Storage time is another factor which can affect pathogen reduction in compost. Faeces can be safely used as a fertilizer after storage either at ambient temperatures for two years or composting at high temperatures for six months (Kaczala 2006). The World Health Organisation (WHO 2006) proposes storage or alkaline treatment as two possibilities to sanitise faeces. The recommendations are different at household and municipal levels, and for commercial systems. At the household level, the storage time should be more than 1 year above 20°C and up to 2 years at 2-20°C. The alkaline treatment is required to last more than 6 months at pH > 9, at 35°C, with < 25% moisture (Gajurel and Wendland 2004).

2.2 USE OF COMPOSTING TOILETS

Internationally, dry sanitation systems (waterless or composting toilets) have been used widely. Their use has received acceptance in rural regions of Europe and the United States (Aburto-Medina et al 2020). Composting or waterless toilets have gained recognition and have been listed in the 2006 World Health Organisation Guidelines for the Safe Use of Excreta and Greywater, and recognised by the Joint Monitoring Programme of the Millennium Development Goals as one of five possible systems of improved sanitation (Olanrewaju 2015).

Historically within a New Zealand context, composting toilets have been confined to isolated domestic dwellings with intermittent use or backcountry huts and walking tracks. In recent years composting toilets have become an alternative on-site wastewater management option for a variety of domestic dwellings in rural and urban settings where wastewater is not reticulated (Anand and Apul 2014). Under the Building Code a waiver is required from the building Consent Authority to have an on-site wastewater system where there is a reticulated sewerage system. Although only a limited number of composting toilets are known to exist in locations with reticulated wastewater (Salmon et al 2004), every region in New Zealand has a percentage of their population utilising composting toilets as their sole method of human waste management. Their reasons may include ethical, environmental, financial and during exceptional circumstances with details given below.

Composting toilets offer an alternative to traditional on-site wastewater management systems, such as septic tanks, by providing an option which may be more financially affordable but, they require a higher level of user interaction and knowledge to avoid risks to public and environmental health (Anand and Apul 2014).

The water and waste minimisation, circular economy and closed loop movements all contain similar views on human wastewater management which may encourage and promote the use of composting toilets for environmental sustainability reasons (Anand and Apul 2014). This is in contrast to many in developing countries who view water-based sanitation (i.e. centralised wastewater treatment plants and decentralised septic tanks with drain fields) as aspirational (Ersson and King 2019). For example, apart from water which may be used for hand washing, composting toilets require no water and therefore minimise water usage. As well as conserving water, the compost that is generated and adequately decomposed, can be applied to the land as a soil amendment and therefore enable the user to create a circular or closed loop system (Ersson and King 2019). In some cases, these environmental views can overlap with philosophies about self-sufficiency and independence from government infrastructure and services, and off-grid living (Anand and Apul 2014). However AS/NZS 1546.2:2008 requires composted solids to be buried in areas where there is limited access, if authorised by the regulatory authority, or removal by a waste contractor.

Composting toilets can be considered a financial alternative for rural and urban wastewater management. In a rural setting where on-site wastewater management systems can range from $15,000 - $40,000 (pers comm Andrew Dakers and Fiona Ambury,10 June 2022) to design and install along with annual maintenance and operation fees, composting toilets may be considered an attractive financial alternative.

Finally, composting toilets are utilised in exceptional circumstances in emergency or disaster situations and may be the only available option to provide sanitary facilities to a population. Examples of this were the Christchurch and Kaikoura earthquakes (2011 and 2016 respectively) in which many urban and some rural residents were forced to utilise a range of on-site waste(water) management systems such as chemical toilets, pit latrines and composting toilets on their properties, due to damaged wastewater infrastructure (ESR 2017). For some homeowners, this practice continued for an extended period of time and in Christchurch reticulated wastewater was not fully restored for 3 years post the February 2011 earthquake (ESR 2017). Public health risks within this particular setting were increased on smaller sections where there was a reduced ability to avoid contact recreation with either, the emergency toilet itself, or the area in which the human effluent was stored or discharged to the environment (ESR 2017).

Commercial availability and uptake of composting toilets in New Zealand shows that there is a demand for this technology and suggests that consumers are using composting toilets in domestic residences as a primary or secondary biowaste management option. However, there is lack of information on the operation and maintenance of these composting toilets.

2.3 PUBLIC HEALTH RISKS DERIVED FROM COMPOSTING TOILETS

Public health risks from the use of composted human waste arise from the presence of pathogenic organisms and chemicals. Healthy human faeces will have low pathogenic and hazardous chemical contaminants. The risk arises from faecal matter arising from sick individuals and the household use of pharmaceuticals and estrogenic compounds.

It is widely recognised that if decentralised wastewater disposal systems, such as on-site wastewater management systems (i.e. septic tanks), are not adequately designed, operated and maintained, public health and environmental issues can arise (Richards et al 2017, Otis et al 2002), and this also applies to composting toilets.

1.2.4 Pathogens

Disease-causing organisms such as viruses, bacteria, protozoa and helminths may be present in human faeces (WHO 2003).

If the conditions of the composting process are appropriate (i.e. thermophilic conditions are achieved), and of sufficient duration, the resulting compost should have a significantly reduced pathogen load and may be deemed safe after a burial period of 6-12 months, which mitigates the potential health risk if the thermophilic temperatures have not been achieved for the required period. The biggest risks are associated with human exposure to waste by handling or disposing of waste during the composting process, or if it is not adequately treated from mismanagement of the composting process. Another risk is the attraction of vectors, such as vermin and insects, which is enhanced by the waste or inadequate processes, thus, it is important to ensure the correct conditions for operation, as described above. Inadequate management of composting toilets can also contaminate the environment or surrounding water and result in indirect exposure to potential pathogens. Although not a direct health risk, a malfunctioning system can also produce odours that can be offensive and further attract vectors.

When considering the operation of the composting process for inactivation of pathogens, compost temperature is considered the most important factor (Kelova 2015). Research has indicated that a compost temperature greater than 50˚C is required to inactivate or destroy pathogens (Nasri et al 2019).

In addition to elevated temperature, the duration of the process is a key component. Many researchers (Darimani et al 2015, Mehl et al 2011, Berger 2010, Schönning et al 2007) have found that 3-4 months is inadequate to inactivate or destroy pathogens and greater than 12 months is a more appropriate length of time (Mehl et al 2011). Where this length of time is not achievable, additional treatments are required to ensure adequate pathogen removal (Jensen et al 2009).

Further research is required to investigate the potential for re-growth of pathogenic organisms either during the maturation phase or after the compost is amended to the soil. Many of the composting toilets in Europe and some parts of USA rely on extended retention time and biological factors including competition for food and predator-prey relationships to eliminate or reduce pathogens. In countries such as Vietnam, China, El Salvador, Mexico, South Africa, additional measures such as raising pH by adding ash and/or lime, desiccation by solar heating and addition of dry materials to reduce moisture levels are used to remove pathogens (Gajurel and Wendland 2004).

Another parameter that can assist in pathogen removal is antibiosis. Aerobic microorganisms can synthesise substances that are toxic to other microorganisms, including pathogens.

If compost leachate is not effectively contained there is a risk of pathogen transport in leachate from the composting pile if the system is not contained. One means of reducing the risk of pathogen transport by leachate is to use a urine diversion composting system. This reduces the amount of leachate which can often contain elevated levels of contaminants, including pathogens.

Escherichia coli is an indicator of faecal pollution and the fate of faecal pathogenic bacteria and therefore has been used to confirm the efficacy of waste treatment systems. However, *E. coli* cannot be reliably used to predict the efficacy of treatment of other pathogens such as viruses and protozoa. There have been limited studies identifying the most appropriate indicator for virus inactivation in composting toilet waste. For protozoan pathogens and helminths most studies have used *Ascaris lumbricoides* due to its persistence in the environment (Mehl et al 2011).

There have been limited studies on the potential inactivation of viruses by composting processes. Factors that affect virus survival in composting systems are high pH, low moisture content, microbial activity, high temperature and the presence of free ammonia. Even with these conditions, the length of time required for adequate inactivation of viruses is lengthy, requiring months to achieve adequate reduction (Guardabassi et al 2003).

1.2.5 Chemical contaminants

The concentration of heavy metals and other contaminants, such as pesticides will be low or absent in faeces, depending on the amounts present in consumed products (Jönsson et al 2004). Higher concentrations will be present in faeces compared with urine, as faeces contains both unmetabolised and metabolised contaminants. However, the concentration of heavy metals and pesticides will be lower than in chemical fertilisers. Table 1 illustrates the concentrations of heavy metals present in various wastes compiled from studies in Sweden.

Table 1 Concentrations of heavy metals in waste materials from Sweden (Jonsson et al 2004)

	Unit	Cu	Zn	Cr	Ni	Pb	Cd
Urine	µg/kg ww	67	30	7	5	1	0
Faeces	µg/kg ww	6667	65000	122	450	122	62
Urine+faeces mixed	µg/kg ww	716	6420	18	49	13	7
Kitchen waste	µg/kg ww	6837	8717	1706	1025	3425	34
Cattle org. FYM	µg/kg ww	5220	26640	684	630	184	23
Urine	mg/kg P	101	45	10	7	2	1
Faeces	mg/kg P	2186	21312	40	148	40	20
Urine+faeces mixed	mg/kg P	797	7146	20	54	15	7
Kitchen waste	mg/kg P	5279	6731	1317	791	2644	26
Cattle org. FYM	mg/kg P	3537	18049	463	427	124	16

Hormones produced within the body and pharmaceuticals will be mostly excreted via urine. The amounts released in faeces and urine is small compared with other sources and likely to have little effect on both the environment and public health. The prolonged process of composting will breakdown hormones and pharmaceuticals. There is a lack of information in the literature relating to the household scale composting of human waste. Most studies have been conducted on municipal waste where the concentrations of organic contaminants are much higher.

Antibiotics are known to be metabolised in the body in only small amounts, leading to a high proportion (50-90%) excreted in urine or faeces in the parent form i.e., unchanged (Hirsch et al 1999). Excreted antibiotics affect the microbial processes occurring in the composting process, leading to reduced degradation rates of faeces (Kakimoto et al 2007). If, however, the composting process can achieve a sufficient thermophilic phase and maturation phase, significant reduction in antimicrobial resistance genes (ARGs) and antibiotics can occur (Werner et al 2022, Huang et al 2021, Qian et al 2016).

Other contaminants present in human derived organic waste such as sewage sludge are mostly surfactants and plasticizers, which should not be present if composting toilets only receive faeces.

1.2.6 Nutrients

Nutrients present in urine are water-soluble and thus easily available for plant uptake. In faeces, a combination of water-soluble and non-water soluble nutrients are associated with the particulate matter. The plant availability of nutrients in faeces is therefore lower than urine. The process of composting over long retention times, and addition of composted material into soil will enable the breakdown of nutrients into plant-available forms. The impact of excess nutrients from the addition of composted faeces and urine will be seen in the environment. This is where careful consideration of the location of the application of urine and compost is required to ensure optimal uptake of nutrients occurs, to mitigate the effects of leaching to the environment.

Nutrient content in urine and faeces consists of nitrogen compounds, potassium, phosphorous and sulphur. In urine the main component of nitrogen is urea, followed by ammonium and creatine (Lentner et al 1981). Once excreted, urea is quickly converted to ammonium (within hours) and once in soil, converted, via microbial processes, to nitrate, which is readily available to plants. In faeces, even after composting a high proportion of organic nitrogen will be present which is not readily available to plants. Once in the soil, most organic nitrogen can be degraded into plant available compounds.

Potassium, sulphur and phosphorous compounds are present in high concentrations in faeces and are readily available to plants. The main issue is loss of these nutrients in leachate before plants can take up the nutrients. To avoid this, application of the composted material needs to be managed to avoid nutrient loss through leachate.

1.2.7 Environmental effects

As our climate continues to change, the United Nations is currently predicting a 40 percent shortfall in freshwater resources by 2030. Composting toilets require no or minimal (if handwashing is considered) water usage and save between 15 – 28% in indoor household water use and therefore provide a water conservation alternative to traditional forms of human wastewater management (Salmon et al 2004). With the prospect of more frequent droughts and floods, drinking water sources are predicted to become increasingly vulnerable to contamination (Anand and Apul 2014). While composting toilets require little to no water, their impact on human health due to climate change may be when nearby drinking water sources are impacted by the discharge of the human composting system to the environment (Ahmed and Ahmed 2017).

2.4 NZ STANDARDS AND GUIDELINES FOR COMPOSTING TOILETS

Composting toilets are a biological toilet system that contains excrement, an added carbon source, toilet paper and sometimes urine. The system relies on unsaturated conditions to enable aerobic microbial breakdown of excrement to a compost material.

According to the AS/NZ Standard (1546.2:2008), the composted end product is required to meet the criteria provided (Table 2). The composted end product is to be buried in soil for 6-12 months, with at least 100 mm covering of soil, where it will not come into contact with consumable plants or surface water (Appendix K, AS/NZS 1546.2:2008). Access to the area needs to be restricted. If burial is not authorised by a regulatory authority it needs to be removed for disposal in a manner approved by the regulatory authority. If the composted end product is to be buried on site, an approved disposal area needs to be identified

AS/NZS 1546.2:2008 addresses design, maintenance, and operation of composting toilets to reduce public health risks. According to the standard, a composting toilet shall meet performance requirements for adequate capacity and watertightness, be well-ventilated, absence of insects and vermin and end product quality.

Note: if urine diversion is used, there is a requirement for this urine or liquid to go to an on-site wastewater system that meets the standards set out in AS/NZS 1547:2012.

Table 2 Requirements for composted end product quality that is regarded as safe and ready for disposal (modified from AS/NZS 1546.2:2008).

Characteristic	Test	Performance requirement
Consistency	Visual	Sample shall contain no recognisable faecal material
Colour	Visual	Good compost is black
Odour	Olfactory	There shall be no offensive odours from the end product immediately following removal from the chamber
Moisture	ASTM D4959-00 (1)	< 75 % by weight
a) Pathogen test Thermotolerant coliforms	Total faecal coliforms as indicator organism, Standard Method test 9221E and 9222D (2)	< 200 MPN/g dry weight
a) *Salmonella* spp	Standard Method test 9260 (2)	Not detected in 4 g dry weight

(1) ASTM D4959:2007 Standard test method for determination of water (moisture) content of soil by direct heating. American Society for Testing Materials

(2) Standard Methods for Examination of Water and Wastewater, 21st edition (2005) or more recent editions. American Public Health Association.

To meet the requirements for the composted end product, the method of sampling and analysis is set out in the standard (Table C1, and below Table 3). As well as the sampling and analysis, a record of the consistency, colour and odour of the sample should be made. The time of sampling is dependent on the type of system used. Continuous process requires sampling at the end of the nominated composting period. After one month and prior to removing the composted end-product, sampling should be undertaken as described (Table 2) to ensure regrowth of bacteria has not occurred. In batch composting systems, sampling should be undertaken in the first batch chamber, and tested after the nominated period. After one month, the composted end-product from the first batch chamber shall be sampled and tested again, to confirm the results of the previous tests and to verify that there has not been any regrowth of bacteria.

Sampling and testing of the system should be undertaken until the requirements set out in Table 2 are met for two consecutive sets of samples. The time between testing should be one month.

Table 3: Sample size, location and number of samples of composted end product to be taken

Representative minimum sample size (weight)	100 grams
Sampling location:	
(a) Continuous system (single chamber)	Three samples to be taken along and as close as possible to the base of the compost pile in the removal zone
(b) Batch system (alternative or circulating chambers)	One sample to be taken from each of the following levels: the base; the middle; and top of the composted end product. Samples are to be taken as close as possible to the centre of the chamber

In addition to AS/NZS 1546.2:2008, composting toilets must comply with the Building Code and Act, Resource Management Act, and the Health Act.

Composting toilets can only be used in areas where mains sewerage system is not available, whether permanently or temporarily (e.g. following an earthquake). This is stated within the Building Code, under the Building Act 2004, unless the building consent authority provides a waiver to this rule. Within the Building Code, Clauses B1, B2, G1 and G14 includes the structure, durability, hygienic parameters, and performance requirements of systems that store and treat (liquid) waste. In addition, any plumbing installation must comply with clauses G12 and G13 within the Building Code.

The Resource Management Act 1991 (RMA) is operated by territorial local authorities and regional or unitary councils. Regional plans are used to manage potential adverse effects on the environment from any effluent produced. Currently, territorial local authorities will give consent under the Building Act to install a composting toilet system. A resource consent under the RMA may also be required.

Composting toilets fall under the Health Act 1956, Section 54, Schedule 3 which states that nightsoil collection and disposal is an offensive trade, which requires authorisation by the territorial local authority and the Medical Officer of Health. A waste contractor that removes composted solids would therefore require authorisation.

2.5 INTERNATIONAL REGULATIONS AND STANDARDS

According to World Health Organisation, if urine is used as a fertilizer of crops for household consumption only, it can be used directly without storage. The likelihood of household disease transmission that results in areas where there is a poor level of hygiene, is much higher than that of transmission through urine applied as a fertilizer (WHO 2006). When urine is collected from many urban households and transported for re-use in agriculture, the recommended storage time at temperatures of 4–20 °C varies between 1 and 6 months depending on the type of crop to be fertilized (Esrey et al 2004).

The World Health Organization (WHO) guidelines recommend that composting of toilet waste should be performed at 50˚C or higher one week to a month followed by two to four months curing time (WHO 2006). Pathogens die in a few days if composting temperatures of 50-60 °C can be reached, however, these temperatures are rarely achieved in a composting toilet, especially in temperate climates (less than 20˚C) (Scott 2002). In most cases in a composting toilet, the volume of the compost is small and heat loss may easily occur (Hill et al 2013). The normal operating temperature range is often mesophilic or ambient (Berger 2010). In these conditions, further maturation times are required for pathogens to die-off (Table 4). Apart from ensuring adequate maturation or composting conditions, the WHO 2006 guidelines recommend further testing to verify the appropriate pathogen reduction (mostly in large scale systems) with < 1000 MPN/cfu *E. coli* / g total solids.

Table 4 Recommended storage treatment of dry excreta and faecal sludge without new additions, before the use at the household or municipal level (modified from WHO 2006).

Treatment	Criteria	Comments
Storage, ambient temperature: 2 - 20 °C	1.5 – 2 years	Will eliminate bacterial pathogens. Regrowth of *E. coli* and *Salmonella* spp. may need to be considered if rewetted. Will reduce virus and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers.
Storage, ambient temperature > 20 – 35 °C	> 1 year	Protozoa: inactivation of schistosome eggs (> 1 month); inactivation of nematode eggs; survival of 10 – 30 % of Ascaris eggs (> 4 months), whereas a more or less complete inactivation of Ascaris eggs will occur within 1 year.
Alkaline treatment	pH > 9 during > 6 months	If T > 35 °C and moisture < 25 %, lower pH and/or wetter material will prolong the time for absolute elimination

2.6 MĀORI VALUES AND SOCIAL ACCEPTABILITY

A reflection of traditional Māori views on waste management is vital to understanding the role that mātauranga Māori (Māori knowledge) can offer decentralised wastewater management practices such as composting toilets. However, for a complete understanding of the greater cultural landscape it needs to be recognised that Māori culture is not homogenous throughout Aotearoa New Zealand and tikanga can adapt to contemporary situations in a manner which is consistent with iwi needs and aspirations (Awatere 2003, Ataria et al 2016). Marsden (1992) states that cultural viewpoints and realities are based on the unique relationships that people have with the natural ecosystems that they occupy. There are, however, traditional and contemporary views on human waste management which require consideration.

1.2.8 Traditional views

Feltham (2021) describes the tikanga frameworks associated with wastewater management from a historical perspective:

> Traditional Māori waste management practices were strongly grounded in cultural beliefs. Human excreta was tapu (sacred, under restriction) by virtue of the relationship between humans and atua (ancestors, deities, spiritual powers) and thus was subject to specific processes to ensure separation from other tapu entities and return of the waste to a noa (safe) status.

The concepts of tapu and noa sought to protect and influence spiritual well-being when considering waste management (Awatere 2003). There were also strict waste management practices that sought to maintain health and environmental protection (Pauling and Ataria 2010). Pauling and Ataria (2010) state that the literature consistently describes the practices of Māori in dealing with wastes and the associated beliefs surrounding particular customs and practices. In their report, *Tiaki Para: a study of Ngāi Tahu values and issues regarding waste*, Pauling and Ataria (2010) list many references that describe the careful and disciplined disposal of human and other biological materials which alongside human faeces included hair and nails (Ihaka et al 2000, Tau et al., 1990, Beattie and Anderson 1994, Beattie and Tikao 1990 and Awatere, 2000). Te Wai-Puanga (1993) states:

> Waste management in Pa (fortified) and kainga (unfortified living sites) of Rongomaiwahine/Ngaati Kahungunu was organised so the waste associated with specific activities was handled and disposed of through a complex set of rules. These practices required separate disposal mechanism and methods for each article. For instance, bodily material was considered and treated separately from the waste associated with food preparation, unconsumed leftovers, mimi (urine) and tutae (faeces) with food scraps, hair or fingernails…Te marere o te toto o whare aitu (menstrual blood) was considered to be extremely hazardous to other people. The material was highly tapu and its disposal was a separate and private matter for women.

Pauling and Ataria (2010) describe historic Māori human waste management as being a common latrine which was located on the outskirts of a settlement with the use of any type of manure for food production viewed as abhorrent.

1.2.9 Contemporary views

Pauling and Ataria (2010) state that there are numerous contemporary views and experiences in relation to human waste management in the form of policies written by iwi, submissions and evidence in relation to particular sewage schemes, Waitangi Tribunal claims, resource consents or court proceedings. It is a commonly held view amongst Māori that the discharge of human waste to water is unacceptable regardless of the level of treatment and that discharge of human wastewater to land is to be encouraged (Pauling and Ataria 2010, Awatere 2003, Feltham 2021). Feltham (2021) states:

> Māori have consistently expressed support for waste management practices which incorporate natural processes including filtration through land and wetlands as a part of the treatment process. Māori have also consistently raised issues with processes that involve discharge of waste, regardless of the level of treatment, into bodies of water.

The above statements recognise that the historical Māori world view on human wastewater management acknowledges the interconnectedness and interrelationship of all living and non-living things (Ahuriri-Driscoll et al 2008). An example of a contemporary view can be described in an Environment Court appeal known as the 'Wellington Biosolids Case' or the 'Living Earth Case' as described by Pauling and Ataria (2010). An appeal in 1998 was brought by Te Rūnanganui o Taranaki Whānui ki te Upoko o te Ika a Maui Incorporated against the Wellington Regional Council, the Wellington City Council and the Living Earth Joint Venture Company against a consent granted by the councils to Living Earth to use municipal biosolids to create compost for public retail and use by the community (Pauling and Ataria 2010). In the Te Rūnanganui evidence which was supported by Sidney (Hirini) Moko Mead (1998) of Ngāti Awa it stated that:

> Excreta is tapu…There is no problem with the return of excreta of body parts to Papatūānuku…What is abhorrent is the idea of associating biosolids with the food chain.

In the same case evidence was presented by Māori in support of the use of biosolids for compost. Morris Te Whiti Love presented evidence that stated (Daya-Winterbottom 1998, 3BRMB):

> The land is seen as the medium by which tapu is made noa and so rendered useable again…The proposal to compost the untreated sewage sludge follows the tikanga to render the tapu sludge noa and therefore usable. To complete the process to whakanoa association of the compost with earth is required so that the material would fall into the cycle of fallowing to become earth or Papatūānuku.

The literature review could not find a specific reference to the use of composting toilet waste from a Māori perspective but Pauling and Ataria (2010) noted a consistent theme of the separation between the human food chain and human waste streams, a view which is widely supported (Awatere 2003, Ataria et al 2016, Feltham 2021).

2.7 SOCIAL ACCEPTABILITY OF COMPOSTING TOILETS AROUND THE WORLD

Social attitudes and perceptions towards excreta vary with age, sex, religion, education, employment, region and physical capacity (Lamichhane & Babcock Jr 2013). The practices that have evolved in relation to waste and wastewater management in one place cannot be readily transferred to other places and warrants a thorough assessment (acceptability study) of the local sociocultural context of the specific community before introducing new technology (Wegelin-Schuringa 2022; WHO 2006).

For example, a study in south Africa, showed that there was lack of understanding about the use and benefits of the urine diverting dry toilet (UDDT) by many community members. The users aspire to own a flush toilet, perceived to be indicative of household wealth. Lack of education concerning the use of the UDDT was evident. (Mkhize et al 2017). A survey in

Hawaii showed that more than 60% are willing to pay extra for the UDDT, while only 22% knew that such systems existed. The survey results indicate that with a public education program, it is possible that most people would be willing to adopt UDDTs (Lamichhane & Babcock Jr 2013). In New Zealand, composting toilets have gone through several phases of popularity. While they are often perceived as an environmentally friendly approach, some people have a less favourable view of the need for storing and emptying composted human excrement (Chen & Roberts 2021).

3. INSIGHTS FROM KEY STAKEHOLDERS

In total 19 individuals responded to the online composting toilets survey. The range of respondents included:

8 Regional Councils

1 Government Department

5 District or Unitary Councils

3 Public Health Units or District Health Boards

2 Industry consultants

The identities of the survey participants and any responses that may identify them, their employer or region have been omitted in this report to maintain the privacy and anonymity of the respondents. The survey included the following eight questions in Table 5:

Table 5 Composting toilets survey questions

1	Council type, district, regional, unitary, or other?
2	Are you happy to name your council? If yes, what council are you responding about?
3	Do you have any policies/guidance related to the use of composting toilets and the potential risks to public health? If yes, which policies/guidance do you use? (i.e. AS/NZS 1546.2.2008, TP58/GD06, G13 Foul Water: Building Code, regional planning rule)
4	Have you had any issues related to composting toilets in your region? If yes, what were those issues and how were they resolved?
5	What do you think is needed in NZ to improve the usage or management of composting toilets and reduce any associated risk to public health?
6	Do you have an issue with composting toilets with regards to tiny homes, mobile homes or self-contained camper vans in your region? If yes, what are those issues?
7	Do you think composting toilets can be a way of sustainably managing human waste? If yes, why and how would this work in your region? If no, why?
8	Would you like to be kept informed of any composting toilets related reports and research? If yes, please provide your email address?

The following sections provide a summary of the responses in terms of identifying relevant composting toilet policies and legislation, description of issues and if they were resolved.

1.2.10 Policies and legislation

The policies and legislation documents that were mentioned by the respondents when assessing composting toilets are described below and separated into those that are applicable at a regional, national, and international level.

Regional policies and legislation

Regional council plans provide clear direction on how natural resources are to be managed within a region and assist regional councils to carry out their functions in order to achieve the sustainable management purpose of the Resource Management Act (1991). The survey respondents identified specific regional plans that assist council staff in assessing various on-site wastewater management systems such as composting toilets. Of consistent mention by a vast majority of the survey respondents throughout New Zealand was the *2004 On-site Wastewater Systems: Design and Management Manual*. Auckland Regional Council. Technical Publication No. 58, also known as TP58. This document is now superseded by *Guidance Document: On-site Wastewater Management in the Auckland Region*, also known as GD06 (2021). As described by the survey responses these two documents have provided consistent direction not only for Auckland Council but also provide guidance for other regions throughout New Zealand. The respondents outside of the Auckland region recognised that Auckland Council has had the personnel and financial resources to create these documents that many of the smaller regions cannot afford to replicate. The guidance about composting toilets that the survey respondents receive from GD06 includes:

- Types
- Design features
- Conditions required for effective composting
- Benefits and disadvantages of composting toilets
- NZ Building Code requirements
- Risks and strategies to mitigate them

Other survey respondents mentioned the Bay of Plenty On-site Effluent Treatment Regional Plan (2006) of relevance to composting toilet guidance.

National policies and legislation

The following national policies, legislation and guidance documents were identified by the survey respondents as regularly assisting them with managing the health risks associated with composting toilets:

- Health Act 1956

The Health Act 1956 gives territorial authorities a duty to '*improve, promote and protect'* public health (Section 23) primarily through the detection and abatement of conditions likely to be offensive or injurious to health. Section 54 of the act relates to sludge collection and disposal.

- Australia/New Zealand Standard 1546.2:2008 On-site Wastewater Treatment Units. Part 2: Waterless Composting Toilets

AS/NZS 1546.2:2008 was the most frequently mentioned standard by the survey respondents and has four objectives:

1) to provide a set of performance statements which outline the requirements for a domestic waterless composting toilet;
2) to provide performance evaluation tests;
3) to provide manufacturers of waterless composting toilets with basic test requirements for a system to function satisfactorily; and
4) to ensure that waterless composting toilets are operated and maintained in a safe manner that meets basic health requirements for the removal of composted or partially composted material.

- Australia/New Zealand Standard (AS/NZS) 1547:2012 On-site Domestic Wastewater Management
- Australian/New Zealand Standard (AS/NZS) 3500: 2021 Plumbing and Drainage

Survey respondents stated that any dwelling that contains a sanitary facility in New Zealand is subject to the rules outlined in the New Zealand Building Act (2004) and the minimum standards provided by the New Zealand Building Code. The building code requires buildings with sanitary fixtures and appliances to have adequate plumbing and drainage to appropriate outfalls or system storage and or treatment. Within the New Zealand Building Code and in particular clause G13 – Foul Water, was noted specifically by several survey respondents as giving them the mandate to protect public health from household wastewater management by safeguarding people from infection or contaminated water supplies.

Survey participants identified two Department of Conservation guidance documents that assist with the management of composting toilets at a national level within New Zealand's national parks.

- Review of Proprietary Composting Toilets (2003)
- Human Waste Management at Back Country Huts and Campsites (2012) *currently being updated*

International policies and legislation

One survey respondent mentioned the Tasmania Parks and Wildlife Service (PWS) *Toilet Design Manual* (2021). This respondent noted that the Tasmania PWS has not had a good experience with composting toilets and are no longer approving their use in a national park setting.

Two survey respondents noted the *Backcountry Sanitation Manual* (2nd Edition) by the Appalachian Trail Conservancy (2021). This document is relevant to low-temperature composting toilets in remote hiking areas of the United States.

A survey respondent identified a key composting toilet document as being the Water Conserving On-site Wastewater Treatment Systems: recommended standards and guidance for performance, application, design and operation and maintenance (2012) published by the Washington State Department of Health. This respondent noted that in Washington State the permitting of composting toilets is done by the county and each county has slightly different approaches. However, the respondent stated that most counties within Washington State recognise the certification of composting toilets using the Non-liquid Saturated Treatment Systems NSF (National Science Foundation) International Standard/American National Standard 41 (2005).

1.2.11 Composting toilet issues and resolutions

Through the survey responses a range of issues were identified that included council consent and compliance, operation and maintenance, and discharge to the environment, followed by if, and how, these issues were resolved. It is important to note that the majority of respondents identified composting toilet issues to be associated with fixed dwellings or tiny homes and that mobile homes (i.e., campervans, freedom campers) were considered a minor contributor to the issues due to the predominant practice of discharging their human waste to official wastewater dumping stations.

Consent and compliance

Many survey respondents stated that the identification of a suitable consenting and compliance pathway for composting toilets was ambiguous at a regional and national level. They also acknowledged that either they don't have an adequate rule framework in place or that they are unsure of how to interpret the use of composting toilets in the context of their regional planning rules.

One survey respondent stated that in their region very few composting toilets have been consented. Most are informal small bucket toilet systems which when the bucket is full it is transferred to a larger on-site composting pile, buried on-site or transported to an official wastewater dump station[2]. Although not in great numbers in their region the respondent noted that these small bucket systems are outside the local council's purview.

A survey respondent stated that within their region composting toilets are not considered to be a permitted activity and that getting consent from the council is fraught with difficulty. This council expects management of a composting toilet to be undertaken by a contractor, not by the homeowner, and for the compost material to be removed from the site by a contractor with personal protection equipment and appropriate health and safety procedures to a council wastewater treatment facility. Since this council cannot force homeowners to remove their waste off-site under a building consent, when human toilet compost is applied to land it triggers the requirement for a discharge permit within this council. This enables the council to monitor and control the application of human composted waste to land.

Some of the councils surveyed however consider composting toilets to be a permitted activity if all the rules of the regional plan can be met. In this case no discharge consent would be required for the application of composted toilet waste to land. One survey respondent stated that for a dwelling that is to be serviced by a composting toilet, such as a tiny home, often that dwelling does not have a connection to the council wastewater network therefore any greywater generated at the site (i.e., kitchen and bathroom) will need to be applied to the section via a designed and consented Land Application system (LAS).

One survey respondent stated that just like on-site wastewater management systems (i.e. septic tanks), very few commercially available composting toilet systems have documentation to demonstrate compliance with Australia/New Zealand Standard 1546.2:2008 On-site Wastewater Treatment Units. Part 2: Waterless Composting Toilets. This respondent stated that currently they have not seen a performance assessment completed on commercially available composting toilet systems at a national level and the

[2] There are approximately 500 dump stations nationwide, many at holiday parks, service stations or sites provided by local councils. Anyone, but most commonly motorhomes and campervans, can dump their wastewater including greywater at these sites for free (https://nzmcd.co.nz/stories/public-dump-stations-in-new-zealand/).

associated documentation of compliance with durability requirements. One respondent stated that AS/NZS 1546.2 (2008) is written for on-site (stationary) composting toilets and do not consider mobile systems (i.e., campervans, mobile tiny homes).

Operation and Maintenance

A common theme among the survey respondents was that people in their region generally do not understand what a composting toilet is, the level of commitment and time that a well-functioning composting toilet requires or how public health risks can be minimised through proper operation and maintenance. The respondents stated that this has created on-going compliance issues within their regions. These issues have included odour, leachate and surface ponding.

One respondent stated that there are issues with '*blanket guidance*' concerning composting toilet operation and maintenance, when in reality there are many and varied models commercially available which require different levels of operation and maintenance and are accompanied by different manufacturer specifications. A number of respondents stated that there are issues with commercially available composting toilets not performing as per the manufacturer's specifications and under New Zealand's climatic conditions. They also noted non-performance during high loading events and odour issues due to poorly functioning systems.

A respondent noted that if a composting toilet is utilised by more than 4 people the system requires frequent emptying (i.e., daily) into a secondary composting pile or chamber to enable decomposition to occur over time. The respondent stated that this process requires users to regularly handle and come into close interact with their waste and creates an increased potential for health risk exposure. One respondent stated that for users of small batch composting toilet systems, a secondary composting pile or chamber will most likely be needed. The secondary composting system is often left to mature over time may be located at the edge of the property in order to minimise human interaction. This however may create an odour, leaching, or vermin nuisance to neighbouring properties, particularly in an urban setting.

A respondent noted the risk that informal unreticulated settlements in rural and urban locations pose to human health due to wastewater management. The respondent stated that within informal settlements there may be several or multiple small dwellings (i.e., caravans, tiny homes and mobile homes) that are congregated on a section which all utilise composting toilets. The human waste may be composted on-site communally or individually or alternatively the human wastewater may be transported regularly to an official wastewater dump station. In operating and maintaining either of these systems the respondent noted that there are health risks. A composting toilet user who transports their waste (i.e., in a personal vehicle) to a nearby dump station is at risk of exposing themselves to handling and spillage of human waste either on themselves or in their vehicle. If the human waste is composted on-site there are handling and vermin risks and the potential for residents or guests to come into contact with the decomposing waste if the property/land size does not provide adequate separation, signage or containment.

User operation was noted as an issue by one respondent when composting toilets are a public sanitation facility. For example, in a national park, rubbish is often thrown into the chamber leading to contamination of the composting material and potentially rendering it unusable as a soil conditioner.

Discharge to the environment

The most common theme from the survey responses was the perception that there is currently no clear guidance for councils when determining what to do with the composted toilet waste. Some respondents stated that they were unsure if composted toilet waste required a resource consent once it was discharged to the environment. These same respondents were unsure at what point (i.e., time) the composted toilet waste was no longer a risk to people or the environment. One surveyed council however considers the discharge of any human waste to land, including human toilet compost, as requiring consent to discharge to land. A survey respondent stated that some composting toilet manufacturers promote the spreading of compost onto the '*garden*' while other manufacturers specify that the compost must be disposed of at an official wastewater dump station.

Several respondents noted that if human waste could not be composted on the user's land/section, due to inadequate land area, the mobile nature of the home or council regulations, then they assumed that these homeowners took their waste to an official wastewater dump station. Another respondent however stated that human waste in their region can often be found '*hole in the ground, the nearest stream, river, over the bank'*.

While some waste disposal behaviour is irresponsible, one respondent stated that the type of people who pursue composting toilets generally do so as a means of creating a sustainable closed loop waste economy within their property and household. They primarily do this to ensure that after a period of time their waste can be applied to their property as a soil conditioner and would prefer not to dump their waste at an official wastewater dump station.

Several respondents stated that the discharge of decomposed human waste to sections can present health risks if the section size is too small to provide for adequate separation from human contact, the material has not been composted adequately or if there are nearby streams/rivers or shallow groundwater utilised for drinking water. One respondent stated that they receive requests for composting toilets in locations that are unsuitable for the application of human waste compost due to nutrient management issues (i.e., nitrate) in some catchments within their region. Another respondent shared this view in that composting toilets do not remove nutrients and therefore present a nutrient risk to the receiving environment.

Resolution of issues

Several surveyed respondents stated that they are not aware of any issues with composting toilets within their region. The majority of surveyed respondents however stated that many of their compost toilet issues within their region have not been resolved and that they are still seeking resolutions. Many respondents noted that composting toilet issues were often resolved when the systems in a rural setting were replaced with a conventional on-site wastewater management system or in an urban setting when household wastewater was connected to reticulated wastewater infrastructure. One respondent has found industry meetings about certified composting toilet systems and servicing requirements to be helpful in contributing to the protection of public health. Another survey respondent stated that they are currently reviewing their regional plan rules in order to improve the human and environmental health outcomes from composting toilet practices.

4. DISCUSSION AND CONCLUSIONS

It is clear from the literature review that the use of composting toilets is increasing globally. Numerous reasons are cited for this increase, including ideology, ethical considerations, financial and environmental concerns over conventional water based systems. Increasing pressure on water supplies have led to calls for low-cost, easy to operate and maintain systems that can reduce the need for water use in waste treatment. The Sustainable Development Goal (SDG) 6 aims to provide clean water and sanitation. Within this SDG, composting toilets are being cited as one of the options to improve water quantity and quality.

The use of composting toilets potentially has many advantages, including:

- minimising the use of water,
- the potential for creating a circular system by providing a fertiliser and soil improver,
- low initial and ongoing costs, depending on the system
- simple maintenance and operation procedures

There are, however, certain disadvantages that need to be considered, due to the risk to health from the manual nature of the typical composting systems. In New Zealand's temperate climate there is a high risk that the optimal thermophilic conditions for composting will not be achieved or will only be achieved for a short time. This means that careful assessment of the stability and maturity (i.e. inactivation of pathogens and breakdown of harmful chemicals) needs to be made and that hazard management practices such as – burial of the composted product for 6-12 months – is part of the process.

The composting toilet literature review and survey insights have highlighted some similarities between the survey respondents understanding of composting toilets and what the literature recommends in terms of composting toilet best practice for the operation and maintenance and its discharge to the environment. For example, a number of respondents noted that they expect and would recommend that composting toilet waste be stored in a decomposing state for a period of 1 year before the waste is discharged to the environment as an end product of the composting process.

Disparities between survey responders and the reviewed literature and policies and legislation were seen. For example, the New Zealand composting toilet standards (AS/NZS 1546.2:2008) state that the composted end product must be buried in soil with at least an 100 mm covering of soil for 6-12 months. It also states within the standard that the composted toilet material must be tested to ensure that it is safe to be discharged to the environment if it is not removed by a waste contractor. There is no evidence from the gathered survey responses that would suggest that authorities have a formal process of checking compliance with the standard.

This composting toilet scoping study has identified some of the public health considerations in terms of their legislation, design, operation, maintenance, and disposal. Findings include:

- Anecdotal evidence of residents taking composted material to a wastewater treatment plant, or waste contractor which is in breach of the Health Act
- Knowledge gaps in some authorities about the Standard and its requirements

- Disjointed approach to managing a composting process
- Lack of knowledge about health implications of manual handling of compost and use in urban areas

This scoping study indicates further investigation is required to provide adequate guidance to key public health decision makers and users. There is a lack of knowledge on the efficacy of composting processes to inactivate pathogens and degrade harmful chemicals. There is also a lack of knowledge about the prevalence and types of composting toilets in Aotearoa New Zealand as the survey made it apparent that systems and disposal may not have the necessary approvals or be compliant with the standard. Clear guidance on the acceptable use of compost end product is also lacking. Currently, the end product is seen as a waste requiring consent for disposal on site or, is required to be disposed of in a conventional wastewater treatment facility. Information is available on the operation and management of composting toilets through literature and council or composting toilet suppliers' websites. It must, however, be noted that most of the available resources fail to clearly state the level of knowledge required to ensure the composting process is effective and the risks of handling composting waste during the stages of composting, transport to the area on site for maturation of the compost and the disposal of the end product.

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APPENDIX A: AVAILABLE COMPOSTING TOILETS IN NEW ZEALAND

A.1 Commercially available composting toilets in New Zealand as of June 2022

- Bambooloo www.bambooloo.co.nz (Bambooloo™)
- Bioloo www.bioloo.co.nz (Bioloo Domestic/Large, Sun-Mar™ – Spacesaver, Sun-Mar™ – Mobile, Sun-Mar™ – Excel)
- Enviro Composting Toilets www.envirocompostingtoilets.co.nz (Aquatron Composting Toilet System, Farmstyle/Back Country Enviro Composting Toilet)
- Green Loo www.greenloo.org.nz (Rota-Loo 650, Rota-Loo 950, Rota-Loo 2000)
- Green Earth www.greenearth.net.nz (RV Pod, Eco Pod 44, Scandi Pod, Kiwi Pod)
- Simple Waste Water Solutions www.swwsnz.co.nz (Short Drop Toilet – Basic/Deluxe)
- Toilets NZ www.toiletsnz.co.nz (Nature's Head® and OGO™)
- Waterless Composting Toilets NZ Limited www.wctnz.co.nz (Clivus Multrum™ – CM Low Profile, Nature Loo™ – Classic 650, Sun-Mar™ – GTG, Nature Loo™ – Mini, Bambooloo™ – Carbon Limited, Bambooloo™)
- Zing Bokashi www.zingbokashi.co.nz (Nature Loo™ – Mini, Nature Loo™ Excelet with chamber screen, Nature Loo™ Classic 850-2, Nature Loo™ Classic 850-3, Clivus Multrum CM2 with chamber screen)

APPENDIX B: NEW ZEALAND EXAMPLES OF COMPOSTING TOILET SYSTEMS

There have been limited studies conducted in New Zealand regarding application of composting toilets. Three examples are provided below:

1- Emergency compost toilet in Greater Wellington

A trial of emergency compost toilets was conducted by the Wellington Regional Emergency Management office (WREMO) in October and November 2012 to determine whether compost toilets could be a viable alternative to port-a-loos or chemical toilets in an event that sewerage systems are disrupted. This trial was commenced with eleven participants with a mixture of households and workplaces with a broad demographic and located in Wellington City. The emergency compost toilet was designed by Green Earth Developments and there was flexibility in the application of the toilets based on the different situation of the participants. This emergency toilet was categorised as a batch composting toilet.

Operation and maintenance: To operate the emergency composting toilet, urine and faeces were collected in separate buckets. Materials such as wood shavings, leaf mulch, and straw were provided for the participants to add to the faeces bucket and the storage container. The urine was diluted with water to reduce the urine odour. After the buckets were filled, the users needed to empty them. Most participants emptied the urine bucket daily and the frequency of emptying faeces buckets depended on the family number and fastidiousness. During the trial, all participants maintained the toilets and storage container in a clean state and used their regular cleaning products to clean the buckets. Use of straw nest in the bottom of the faeces bucket helped with emptying it. The storage containers were kept in the shade. All these activities helped to reduce odour in the toilet and the storage container.

Waste disposal: At the end of the trial, all solid waste material was collected and disposed of at the Wellington southern landfill. At the end of the trial, a survey showed that most of the participants were willing to use the material as compost.

Public health issue: Public health issue of the emergency compost toilet was not investigated in this report.

Attitude and perception: Many of the participants were anxious at using the compost toilets on the first day of trial, but they adapted to the compost toilet after a few days. At the end of the trial, a survey showed that all the participants showed a positive attitude towards using the compost toilet in the longer term (up to 3 months)(WREMO, 2012).

2- Landcare research building

Composting toilets were installed in the Landcare Research Tamaki building in Auckland, New Zealand. Seven individual toilet pedestals were connected to two Clivus Multrum (2001) composting bins. The bins were gravity-fed from the male and female toilets and used no water for flushing. According to the information obtained from WCTNZ website (https://www.wctnz.co.nz), the Clivus system is based on the continuous composting process in one large chamber, as against multiple smaller chambers that require a restart of the process after emptying. As the organic material decomposes it reduces in volume by up to 90%. The compost pile is therefore always “shrinking in the middle” whilst new material is being added to the top, and finished compost is removed from the bottom of the pile when appropriate.

Operation and maintenance: There is no information available regarding how this type of composting toilets were operating and maintained in the Landcare research Building.

Waste disposal: There is no information available regarding how waste disposal was conducted.

Public health issue: In this project, the compost product was shown to compare favourably with New Zealand Standards and commercially available composts where contribution to plant nutrition is claimed, but the compost has yet to be used on-site because of concerns about its safety. This is due in part to a lack of policy regarding appropriate handling and use of the composted material.

Attitude and perception: It was reported that Staff satisfaction of the composting toilets has increased during their 3-year operation and, in June 2007, 78% of staff said that they were completely or beyond satisfied with using the composting toilets (Trowsdale et al., 2011).

3- Falls Hut on the Routeburn Track

In this case study, two Soltran™ composting toilets were built at Falls Hut on the Routeburn Track (Fig2). They were installed as an experimental toilet. Soltran™ is a solar composting toilet designed to generate heat naturally by using the direct solar incidence. The Soltran was purchased from Environment Equipment, Australia.

Operation and maintenance: After some months of operation, the composting toilet was opened, and some issues were identified. Firstly, the compost temperatures were not as high as the manufacturer’s claims. Secondly, the evaporator tanks had to be drained of urine, on two occasions in the first year. After identification of these issues in the existing composting toilet, Chapman (1993) started to overcome the problems and improve the quality of the compost.

Chapman found that separation of urine and faeces at source and auxiliary heating could most improve composting performance in an existing toilet. Chapman successfully concluded that high temperature composting requires a small, sophisticated composting chamber, while in the ambient temperature composting, these toilets will need to take ambient temperature into account by sizing the surface area of the receiving chamber accordingly. Regarding the maintenance, it was reported that emptying the toilet was not a difficult task.

Waste disposal: There is no information available regarding how waste disposal was conducted.

Public health issues: It was reported that the quality of compost was generally good.

Attitude and perception: N/A