MODERN APPROACH FOR WATER RENEWAL IN SINGLE TOILET SYSTEMS USED ON TRAINS, BOATS, COACHES AND MOTOR HOMES

By Lydia J. Kavanagh

SUSTAINABLE TOURISM CRC

TECHNICAL REPORTS

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Summary

There is a necessity for passenger vehicles, such as boats, coaches, trains and motor homes, to provide toilet facilities when journey times exceed a few hours. The waste from these toilets must then be stored and discharged at a specified facility or treated on board.

Environmental sustainability in the tourism industry is becoming more desirable and hence there is a need to address single toilet systems on vehicles in terms of water use and its potential for renewal. Solutions that satisfy the environmental sustainability criterion may not necessarily satisfy economic and social sustainability criteria. The selection of a single toilet system will require a triple bottom line approach with the needs of users/ customers and the final system cost identified and incorporated in the final solution.

In terms of environmental sustainability, an ideal system would not require water for toilet flushing and hand cleansing would be achieved through biodegradable moist towelettes. The latter would be disposed of either separately or to the toilet. This negation of the need for flush water means that there is no need to store flush water on the vehicle and that there is a smaller volume of waste to treat. Alternatively a low-flush system could be utilised whereby the flush water enters the cistern via a hand basin thus reducing the requirement for fresh water as it is effectively used twice. It should be noted that these systems may not be ideal in terms of social acceptability; user expectations may be that toilets are flushed and hence this would preclude the use of a dry toilet system. Dry toilets tend to be less expensive to purchase and operate than their flushing counterparts and hence economic sustainability goals should be met.

The characteristics of urine and faeces are such that they are far more easily and economically treated if kept separate. Urine, containing most of the nutrients, can be stored for a period of 6 months to ensure no pathogenic contamination and then it can be applied to land thus allowing nutrients to be recycled. Faeces, containing most of the bacterial contamination, can be composted or dehydrated and also applied to land as a soil conditioner. Both composting and dehydration significantly reduce the volume of faeces. Such a system would reduce treatment requirements and the need for chemical and energy inputs thus increasing environmental sustainability. However, as previously discussed, selection of such a system would require both social and economic goals to be met.

The requirements for toilet systems are diverse being a function of vehicle type, discharge requirements, passenger number, and passenger expectation amongst other. It is possible, and currently practiced, to completely treat any wastewater produced by the use of toilet facilities but at a high capital and energy cost as these systems employ membranes. Such systems are only economical on the larger scale such as that found on a train.

Smaller vehicles may find that other systems such as the use of incineration toilets or systems that employ chemical oxidation through the electrolysis of seawater are more applicable. These systems are commercially available.

Innovations such as small-scale distillation and membrane technology have yet to be proved and so are not yet available for immediate use. The development of these technologies should be monitored however, as they may offer a viable alternative to the current systems.

Chapter 1

Introduction

The development of many new technologies relating to wastewater treatment and water reuse allows groundbreaking approaches to some very old problems. One of these is the problem of how to manage wastewater from single toilets, such as those used in trains, boats, and coaches/ motor homes. Traditionally this wastewater has been directly discharged or stored, with or without chemical addition, until discharge is possible at a designated port. Today's environmentally sensitive tourist and stricter legislation requires that wastewater be handled in a responsible and environmentally sustainable fashion.

The use of membranes, urine separation at both the source and after collection, vermiculture and electroflocculation may provide the key to environmentally sustainable wastewater handling through a combination of these new technologies.

For instance, there are already a number of successful toilet systems available worldwide using urine separation technologies which reduces treatment requirements and allows nutrients to be recycled through direct application of urine onto agriculture. But much more could be done, for example if separation technology was combined with membrane treatment, it could provide a simple yet effective means to recycle the water used for flushing back to the same toilet. The membranes would ensure the water is free of pathogens and therefore poses no health risk and the separating toilet would ensure that the treatment of the waste materials would require a very much smaller system as the wastewater would be more highly concentrated and of a lower volume than currently is the case.

This technology would not be suitable in all circumstances; depending on the usage of the single toilet, requirements for discharge/reuse and availability of freshwater, different methods of treatment will be required. This document explores currently available technology as well as innovations and provides a general decision matrix for the selection of single toilet systems.

Importance of Research / Significance / Problem

Water use minimisation and reuse are currently very important issues that are being developed and implemented on both national and international levels. The Queensland government have put in place a strategy:

'The Queensland Water Recycling Strategy provides a framework at all levels of government to encourage the adoption of sustainable water recycling to better manage our water resources for this and future generations, and to support economic growth while protecting the environment and safeguarding public health.' (Sherman 2002)

Whilst the research documented in this report is significant in general terms, the development of a system that minimises water requirement and/or allows for water reuse with respect to single toilet systems will have the largest impact on the tourist industry.

This research is therefore of interest to tourism operators who, by the remote nature of their services, are not able to use public conveniences and hence are required to provide an alternative. To date, interest has been shown by rail operators and boat charter companies as currently there is no industry-adopted standard or preferential system.

Research Aim

The research documented in this report comprises a scoping project for environmentally sustainable, small, mobile 'toilet' systems to be used on boats (up to 20 passengers), trains, and road vehicles where such systems are required.

Environmental sustainability for such systems hinges on:

- restricting water usage;
- reducing chemical and electrical input;
- recycling nutrients; and
- Reusing treated wastewater.

Environmentally sustainable single toilet systems will not achieve implementation without satisfying economic and social criteria also. Systems need to be acceptable to the user/ customer as well as being comparable, in terms of capital and operating costs, to existing systems. Even though this research focuses on environmental sustainability, it is understood that a triple bottom line approach to system selection is required and comments to this effect are made throughout the report.

Contents of Report

This report details the demands of potential system users, legislative requirements, existing and innovative technologies, and supplies a general decision matrix providing an existing system or, where systems do not exist, a more applicable system for possible development.

Chapter 2 (Requirements) details the requirements of single toilet system users and approximates the volumes and concentrations of the wastes produced. This section also outlines the legislation connected with waste disposal for motor vehicles.

Chapter 3 (Existing Systems) describes a number of existing commercial systems that are commonly used. Recent innovations including membrane technology and urine separation are outlined in Chapter 4 (Innovations). Each of these sections concludes with a table comparing the discussed systems.

Chapter 5 (Single System Design) presents design matrices that allow single toilet systems to be selected. These design matrices are configured such that it is not necessary to read the whole report. The reader may proceed directly to this section, utilise the decision trees and be directed to the section within the report containing the pertinent information.

The report is concluded in Chapter 6 (Conclusions and Recommendations) with recommendations for further work and information dissemination.

Chapter 2

Requirements

Introduction

In order to specify systems that are environmentally sustainable, it is important to understand the requirements for single toilet systems in terms of both design values and legislative requirements.

This section therefore details estimates of volumes and concentrations of wastewater produced on an equivalent population (EP) basis and also on the basis of equipment used. The current systems of operation are also summarised along with the legislative requirements for the different types of single toilet systems.

Design Values for Wastewater

Volume

It has been estimated that toilets are responsible for 20% of the average suburban household water usage with each toilet being flushed approximately 6 times a day (Yarra Valley Water 2000). On a per capita basis, it has been estimated that each person requires an average of 1 faeces flush/d, and 4 urine flush/d (Li et al. 2001).

Estimates of wastewater volumes quoted in literature are detailed in Table 1 and Table 2.

Table 1: Estimates of wastewater volume per person

Source	Amount (L/person.d)	Reference
Yellow water (urine)	1.1	(Esry et al. 1998) NOTE 1
	1.4	(Otterpohl 2002) NOTE 1
	1.5	(Anonymous 2003) NOTE 1
Faeces	0.07 – 0.14 kg	(Esry et. al. 1998) NOTE 1
	0.1	(Otterpohl 2002; Anonymous 2003) NOTE 1
Toilet (low flow)	52	(Vinneras & Jonsson 2002) NOTE 1
	35 - 73	(Metcalf & Eddy 2003)
	18 – 36	(Yarra Valley Water 2000)
	25	(Li et al. 2002)
Toilet (composting)	1	(Li et al. 2002)
Toilet (vacuum)	5	(Li et al. 2002)
Toilet (separating)	10	(Li et al. 2002)
Public lavatory, roadside rest area, visitor centre	15 (11 – 19) NOTE 2	(Metcalf & Eddy 2003)
	11.4 (7.6 – 15.2)	(US Army 1999)

NOTES: 1. Values have been converted to daily figures from yearly figures. 2. Figure without brackets is average; figures inside brackets represent range.

Table 2: Estimates of wastewater volume per use

Source	Dual flush amounts (L/use)	Reference
Toilet (standard)	15 – 23	(Metcalf & Eddy 2003)
	12	(Australian Bureau of Statistics 2002)
Toilet (low flow)	6 – 13	(Metcalf & Eddy 2003)
	4 – 8 3 – 6	(Australian Bureau of Statistics 2002)
	3 - 6	(Yarra Valley Water 2000)
Toilet (vacuum)	1	(Li et al. 2001)
Toilet (composting)	0.2	(Li et al. 2002)
Toilet (separating)	0.2 – 0.9	(Li et al. 2002)
	0.1 (urine) 4 – 9 (faeces)	(Vinneras and Jonsson 2002)
Washbasin	8 – 11	(Metcalf & Eddy 2003)
	4 – 8	(US Army 1999)
	5	(Australian Bureau of Statistics 2002)

The values in Table 1 and Table 2 provide design guidelines for single toilet systems. As the design of a single toilet system will be specific to the situation and number of users, it is recommended that these tables be consulted prior to detailed design and after system selection (Chapter 5), to determine the best values for use.

Concentration of Pollutants

Table 3 summarises the pollutants in blackwater, which is toilet flush water containing toilet paper, urine and faeces. Blackwater contains most of the nutrients, pathogen bacteria and medicament residues found in sewage derived from domestic sources (Li et al. 2001).

Table 3: Blackwater strength

Parameter (mg/L)	(Environmental Management Pty Ltd 2000)	(Rasmussen et al. 1996)	(US EPA 1980)
BOD	210 – 560	250	280
COD	940 – 1930	-	-
TOC	110	-	-
TSS	560	220	450
Organic N	56	25	-
NH_4-N	14	25	-
TKN	69	-	-
NO_x-N	0.42	-	-
Total N	70 – 167	40	140
Total P	7.6	12	20
Faecal coliforms (cfu/100 mL)	5.3×10^7	-	-

Blackwater can be further broken down into faeces (brown water) and urine (yellow water). The constituents of these portions are shown in Table 4 and Table 5.

Table 4: Brown water and yellow water characteristics

Brown water (g /capita.d)	Yellow water (g /capita.d)	Blackwater total (g /capita.d)	Reference
Nitrogen			
1.8 – 4.9	7.5 – 13.3	9.3 – 18.2	Gootas 1956
1.5	12.2	13.7	Popel 1993
	15.3	-	Anonymous, 2003
	9.2 – 13.8	-	Larsen & Gujer 1996
	4.1 – 5.5	-	Vinneras & Jonnson 2002
1.1 – 1.4	9.5 – 11.9	11.0 – 13.7	Otterpohl 2002
Phosphorus			
0.8	1.0	2.1	Otterpohl 2002, Anon 2003
	0.4 – 0.5	-	Vinneras & Jonnson, 2002
Potassium			
0.6	2.7	4.9	Otterpohl 2002, Anon 2003
	1.0 – 1.4	-	Vinneras & Jonnson, 2002
COD			
38.6	9.9	82	Otterpohl 2002

Table 5: Wastewater constituents (Hellstrom 2002)

Source	g/capita.d	Grey water (%)	Urine (%)	Faeces (%)	Blackwater (%)
COD	165	50	-	-	50
BOD	66.1	50	-	-	50
Total phosphorus	2.2	28	48 50 – 80 Note 1 50 Note 2	24	-
Total nitrogen	13.3	7	82 80 Note 1, 2	11	-

NOTES: 1. Maurer and Larsen 2002; 2. Larsen et al. 2001.

It has been estimated that a family of 4 would need a compost storage of around 8 m^3 (Li et al. 2001).

Once again, due to the specific nature of single toilet system design, these tables should be consulted prior to design to determine the most applicable values. There is no one value that can be used in all cases.

Operators

Rail

Trains used to transport passengers with transport times longer than a couple of hours generally provide both toilet and hand basin facilities. In addition, sleeper carriages may offer passengers shower facilities and dining carriages will usually have an attached kitchen. The sources of wastewater from a train can therefore be summarised as:

- blackwater (toilet flush, urine, faeces and toilet paper);
- greywater from hand basin;
- grey water from shower facilities; and
- wastewater[1] from the kitchen.

It is the blackwater and associated hand basin grey water with which this report is concerned. Greywater from the shower is not considered in this report as it:

- is a convenience that is not offered on all trains,
- has a much larger volume, and hence significantly different storage and treatment considerations, and
- is not so closely connected with the toilet as is hand basin water.

Historically, wastewater from train bathrooms and toilets was directly discharged onto the railway tracks when the facilities were used. To avoid nuisance at stations, a sign in the bathrooms asked passengers not to use the facilities whilst the train was stopped at a station.

There were a number of other problems (Semco 2003) associated with the practice of direct discharge including:

- damage to the environment,
- unhygienic working environment for railway maintenance staff,
- increasing train speeds pulverised the waste from the original drop causing windows and door handles to be soiled, and
- tunnels occasionally causing the drop to reverse due to pressure changes.

For these reasons, direct discharge has been discontinued, or is in the process of being discontinued, in most countries over the past couple of decades. Wastewater is now commonly stored and emptied at railway station discharge facilities.

To reduce the volume of waste many trains employ vacuum toilets that flush the toilet with a minimal volume of sterilising chemical. These systems are prone to blockage and require emptying every 3 days (Clarke 2002).

Queensland Rail (QR) is currently retrofitting retention toilets to their long distance Traveltrain rollingstock (Carter 2003). Electrical/ pneumatic toilets, supplied by Sanivac, expel the waste to a retention tank installed on the carriage’s underframe which is decanted at facilities in Brisbane, Rockhampton and Cairns.

Both the Rockhampton and Cairns Tilt Trains and a number of QR's Citytrain carriages have a similar system installed. The Kuranda Tourist Train has a smaller capacity chemical toilet installed. This toilet has a self contained retention tank which stores and treats the waste prior to it being decanted in Cairns (Carter 2003).

Boat

Boats generate a number of different wastewaters depending upon the size of the vessel. Smaller vessels will generate blackwater and greywater from hand basins whereas larger vessels may also generate wastewater from shower and kitchen facilities.

It is the blackwater and greywater from hand basins with which this report is concerned. Untreated discharge of this wastewater can reduce water quality, pose a human health risk and decrease the visual aesthetics of waterways.

There are 5 types of maritime sanitation devices (MSD) for dealing with sewage on recreational and small fishing boats (Central Coast Board 2003):

- Type I which break up the sewage, disinfect with chemicals and then discharge the sewage overboard (faecal coliforms must be less than 1000 cfu/100 mL and there must be no visible floating solids for discharge);
- Type II which treat sewage through maceration and biological decomposition to a higher quality than Type I (faecal coliforms are less than 200 cfu/100 mL and suspended solids are reduced to less than 150 mg/L);

[1] Wastewater generated in the kitchen is generally not classified as greywater due to the high contamination by fats, oil and grease.

- Type III comprising a holding tank containing deodorisers and other chemicals[2] that is pumped-out and rinsed at on-shore station;
- direct discharge (i.e. without treatment) to the ocean where allowable; and
- portable self-contained toilets that are emptied at pump-out stations[3] or proper disposal sites.

Coaches / Motor Homes

Coaches generate only blackwater and greywater from hand washing. Motor homes may have additional water from showers and kitchen facilities but these should be treated separately from the blackwater with which this report is concerned.

Free discharge of wastewater from road vehicles could result in both land and water contamination, pose a human health risk and decrease local aesthetics. It is therefore unacceptable on many different levels.

Generally, coaches and motor homes employ either a cassette or blackwater holding tank to store toilet waste until discharge is possible at a designated dump point. Cassettes are small in volume to allow manual removal and emptying whereas holding tanks allow for a greater volume of waste and hence longer periods without requirement to discharge. Blackwater tanks can be difficult to empty especially if the point of discharge is difficult to access.

It is common practice for coaches and motor homes to employ a chemical product to prevent odour nuisance. This is especially important in coaches where customers are transported in an enclosed space which includes the toilet.

Coach toilets are usually drained, hosed out and re-primed with chemicals prior to a journey. Periodically, a more thorough cleaning is required and the toilet is filled and drained two to three times. Bleach may be added to the final fill, and stored overnight to ensure that any bacteria build up within the toilet system is eliminated (Harris 2003).

Legislation

Rail

Australian railway operators are gradually updating facilities on trains such that they are compliant with the *Environmental Protection Act 1994* and the *Health Act 1958*. These acts require that discharges to the environment be managed so that they do not adversely affect the receiving environment and that conditions which are offensive or dangerous to public health are prevented.

Boat

In general, the International Maritime Organisation (IMO) regulations prohibit vessels from discharging sewage within four miles of the nearest land, unless they have in operation an approved treatment plant. In addition, discharges within four to 12 miles of land must be broken down, diluted and disinfected prior to discharge.

Although the IMO is only concerned with vessels of 450 GRT[4] (gross registered tonnage) or greater, its regulations are adopted by the Commonwealth and this then filters down to state level (Kavanagh 2004). Therefore the IMO sewage regulation can be taken as indicative of that which will be eventually adopted by all Australian states.

There has been a proposal for the development of a national standard for onboard sewage treatment systems and Maritime Safety Queensland (MSQ) is undertaking to monitor developments and provide input where necessary.

In New South Wales, the discharge of untreated sewage is prohibited in all waters and there are 'no discharge' zones for treated sewage. There is also legislative requirement for some commercial vessel classes to install toilets and holding tanks (*Protection of the Environment Operations Act 1997*; Management of Waters and Waterside Land Regulations – New South Wales).

The New South Wales system of regulation is not without controversy. There is conflict between the regulators and boat owners over:

- no discharge zones with respect to Type I and II MSD's as these units treat sewage to a level comparable to municipal sewage treatment plants and discharge is thought to have a negligible environmental effect in comparison to some other discharges (non-point, septic etc.); and
- the relative scarcity and inaccessibility of pump-out stations, both in terms of boat usage and operational hours.

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2 The use of formaldehyde is discouraged and the use of biodegradable toiletry products encouraged.

3 Pump-out systems used in conjunction with Type III MSD's are designed for use by larger boats with holding tanks. They incorporate a pump and hose arrangement to remove wastewater from the boat and are connected to the main sewer or an on-site waste treatment system. Boat sewage hoppers are designed for boats that use a portable toilet. The portable toilet is removed from the boat and emptied directly into the hopper which is connected to the sewer.

4 These vessels typically carry a crew of 15 if carrying freight or can carry around 100 people if a passenger ship (Kavanagh 2004).

In 2003, Maritime Safety Queensland[5] (MSQ) brought out the Transport Operations (Marine Pollution) Amendment Regulation which amended the *Transport Operations (Marine Pollution) Act (TOMPA) 1995*. The original act linked holding tank requirements to the vessel's length and did not take account of the amount of sewage likely to be generated. In addition, even if a vessel was fitted with a toilet and holding tank, there was no requirement preventing discharge directly into any coastal waters (Maritime Safety Queensland 2003).

The amendment, which took effect on 1 January 2004, prohibits the discharge of untreated and treated sewage in the waters of a boat harbour, canal, marina and highly protected areas of a marine park. Untreated sewage also cannot be discharged in smooth waters (rivers, creeks, estuaries etc.), in the vicinity of fisheries resources, reef, or a person in the water and in various other designated sensitive waters. Treated sewage may be discharged in some areas but this will depend on the amount of sewage and the degree of treatment.

Sewage treatment must be capable of achieving treated effluent containing no more than 75 faecal coliforms/100 mL. Other sewage quality characteristics may be specified in the future.

As a result of the amendment, many vessels operating in Queensland waters will need to adopt 'onboard sewage management measures if sewage is likely to be generated. The MSQ Impact Statement (Maritime Safety Queensland 2003) indicates that systems could include:

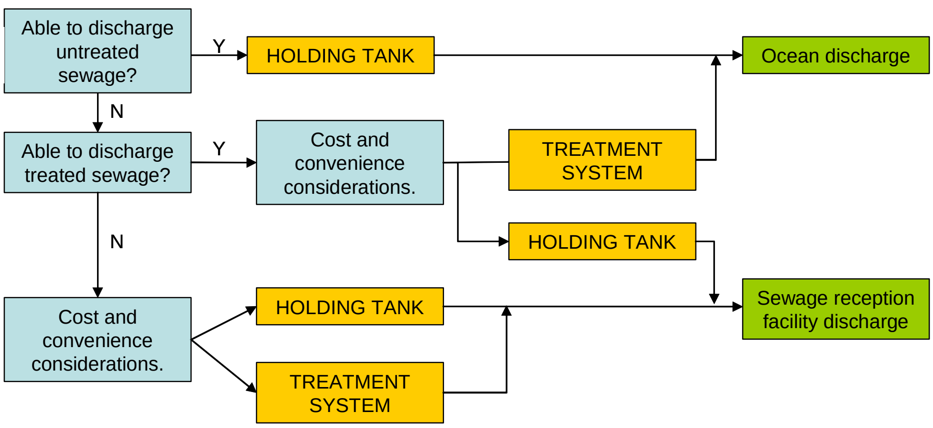
- portable toilets (costing around $150);
- holding tanks (costing from around $300 for 2 persons to $500 for a 4 person tank; and/ or
- sewage treatment systems (costing around $2000 to $3000 including a holding tank).

MSQ recommends that boat owners select the most appropriate system by considering the following factors:

- 'the discharge restrictions in the waters where the vessel will be located;
- the number of persons likely to be on board;
- duration of the trip;
- whether the vessel would be anchored overnight or at a marina;
- whether a marina or public toilets will be available;
- the availability of sewage pump-out and other reception facilities;
- the boat design and specification limitation for installation of a holding device, whether fixed or portable, or a treatment system;
- consideration of adequate power supply for operation of an onboard treatment system' (Maritime Safety Queensland 2003).

The outcomes of these considerations are illustrated in Figure 1.

Figure 1: Onboard sewage management decision tree



Coaches / Motor Homes

Wastewater from coaches and motor homes is required to be discharged at a dedicated discharge point in order to ensure that the wastewater is treated and disposed of compliant to legislation and local council requirements. Free discharge is not permitted.

Water Reuse for Toilet Flushing

There is no national unified approach to water reuse in Australia; each state has different legislation with respect to greywater, roof water and stormwater. Under the *Environmental Protection Act 1994*, discharges to the environment must be managed so that they do not adversely affect the receiving environment and the *Health Act*

5 A division of the Queensland Government.

1958 makes provision for the prevention and abatement of conditions and activities, which are, or may be offensive or dangerous to public health. The *Guidelines for Sewerage Systems – Use of Reclaimed Water* (ARMCANZ/ANZECC/NHMRC 2000), which is currently being reviewed, addresses only recycled water arising from municipal sewage treatment plants.

The *New South Wales Health Accreditation Guideline for Domestic Greywater Treatment Systems* accepts less than 10 thermotolerant coliform/100 mL if the water is to be used for toilet and urinal flushing and laundry use. The Victorian EPA's *Guidelines for Environmental Management: Use of Reclaimed Water*, give the following water quality objectives (medians) for uncontrolled non-potable public use[6]:

- <10 *E.coli* org/100 mL,
- turbidity <2 NTU (pre-disinfection, maximum 5 NTU),
- <10/5 mg/L BOD/SS,
- pH 6 – 9 (90^{th} percentile), and
- 1 mg/L Cl_2 residual after 30 minutes (or equivalent disinfection).

In addition, the following must be monitored:

- pH, BOD, SS, *E.Coli* weekly,
- turbidity and disinfection efficacy continuously,
- disinfection daily, and
- nitrogen and phosphorus.

Toilet flushing is to be via a closed system that allows no direct human contact with reclaimed water.

The Japanese criteria for water reuse for toilets is that the BOD be less than 20 mg/L, the COD less than 30 mg/L, and the coliform count less than 10 organisms/100 mL. In addition, the smell and appearance should not unpleasant (Mitsubishi Kakoki Kaisha Ltd 2003).

The *Queensland Guidelines for the Safe Use of Recycled Water* (Queensland Government, 2003) has been produced as a draft for technical review and comment only. It classifies the water with respect to use and advises water quality criteria as shown in Table 6; all waters must have a pH value between 6 and 8.5.

Table 6: Classification of recycled water for use in Queensland (Queensland Government 2003)

Class	**Criteria for class of water**				**Use**
	Thermo-tolerant coliforms (cfu/100 mL)	**Turbidity (NTU)**	**SS (mg/L)**	**Chlorine residual (mg/L)**	**(See note for description of 'high', 'medium' and 'low')**
A+	< 10	< 2	-	> 1	High human contact with medium risk of ingestion.
A	< 10	< 2	-	> 1	High human contact with low risk of ingestion.
B	< 100	-	≤ 30	-	Medium human contact, minimal risk of ingestion.
C	< 1000	-	≤ 30	-	Low human contact, minimal risk of ingestion.
D	< 10 000	-		-	Non-food chain, no human contact.

Note: High = direct contact with recycled water could occur during normal use of the water.
Medium = direct contact could occur but only with people directly involved in recycling
Low = contact only occur accidentally or where people are wearing protective clothing.

All of the applications detailed in Table 6 require development and implementation of a Recycled Water Safety Plan incorporating risk management. At this stage of the guideline development, reuse for toilet flushing is not recognised.

Summary of Criteria

Single toilet systems for trains, boats and motor vehicles, will be designed on the basis of a number of considerations:

- the type of vehicle and the number of passengers it will carry;
- the motivation of the operator to provide an environmentally sustainable system;
- the sensitivity of passengers to odours and various alternative technologies;
- the amount of space available for a toilet and/ or treatment system;
- the associated costs of treatment and discharge;

[6] As would be the case if water was reused for toilet flushing.

- the legislative requirements with respect to opportunities to discharge wastewater;
- the legislative requirement to treat wastewater and the level to which it is to be treated; and
- the opportunity to reuse the treated wastewater.

As these considerations will be different in each situation, there will be no one system that is applicable in every case. Instead each system will need to be individually designed to suit the operator and the intended use.

Chapter 3

Existing Systems

Introduction

This chapter provides a summary of existing, tried and proven single toilet systems[7]. Details given include power requirements, dimensions, costs (where obtainable), maintenance requirements, and suppliers.

The section is completed with a critical comparison of the discussed systems on the basis of requirements, sustainability and applicability to the various vehicle types.

Composting Toilet

System Basics

The successful operation of composting toilets relies on two basic actions:

- liquid being evaporated or separated such that aerobic conditions are maintained; and
- solid wastes being biologically decomposed by aerobic bacteria into compost.

The composting toilet should therefore provide the optimum environment for the biological decomposition of moist (30 to 50% moisture content) human excrement under sanitary, controlled aerobic conditions. Environmental factors such as air, heat and moisture therefore need to be controlled to optimise the process, (US EPA 1999).

Most composting systems incorporate fans, heaters and/or mixers to maximise performance and minimise odours. Fans are used to remove odours, heat, water vapour and the by-products of aerobic decomposition as well as to keep the contents aerobic. Often a bulking agent such as straw or woodchips is added to accelerate the biological process by providing spaces for aeration and microbial colonisation.

Waste is broken down to 10 to 30% of its original volume into an oxidised, humus-like end product which can usually be utilised as a fertiliser and/ or soil conditioner. The requirement for compost removal from the toilet system varies from 3 monthly to yearly.

The composting toilet is highly cost effective with low power, no waste transport and no flush water requirements. However systems must be maintained and properly operated or odours can be generated and the job of removing the end-product can become highly unpleasant. The price of composting toilets may range from US$750 to US$3,000 plus installation. Energy costs may be appreciable for year-round use (University of Minnesota 2002).

Types of Composting Toilet

The simplest composting toilet utilises a drop and store system. This can be on a batch (e.g. Carousel) or continuous basis (e.g. Clivus Multrum,
Figure 2) each with an associated shortcoming:

- 'Continuous composting toilets may allow fresh material and pathogens deposited at the top of the pile to contaminate successfully decomposed end-product at the bottom of the pile.' (Commonwealth of Australia 2003); and
- Batch systems require storage vessels to be changed over and therefore require more room. This may be turned to an advantage with respect to vehicular systems in that storage of full containers need not be on the vehicle. It does require that a dedicated space, allowing a compost retention of time of between 2 and 4 years (Li et al. 2001), be assigned somewhere else however.

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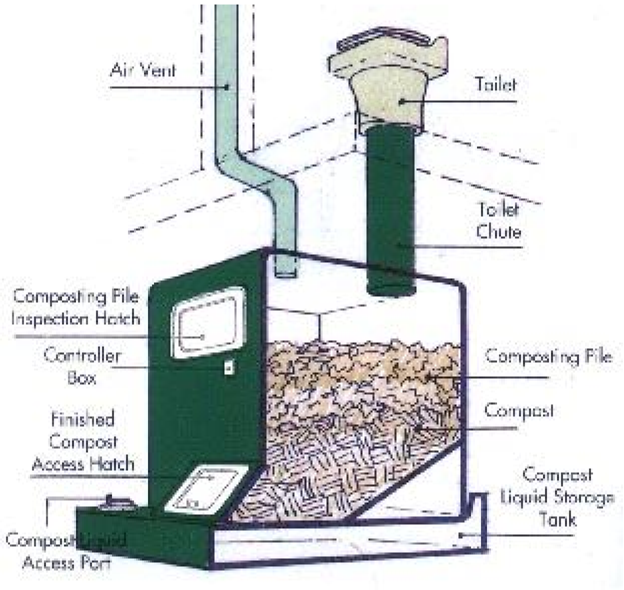
7 The list of proprietary systems given for each system is by no means exhaustive but is indicative of the variations in type available for each system.

Figure 2: Clivus Multrum system (www.edm.ca/clivusmultrum.html)

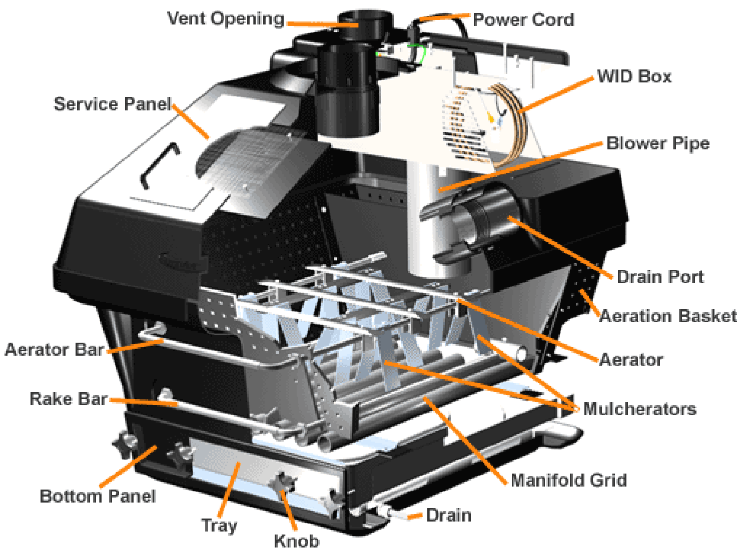


Both the batch and carousel systems are not usually portable but are hard-wired into a residence or toilet block. However, these simple systems can be made highly mobile through the use of a bucket, seat, and biodegradable liner system (Berger Biotechnik GmbH 2002). Adsorbent material such as bark chips, wood clippings, earth or shredded material are placed in the liner and more adsorbent material are added after defecation. This system would probably be of more use for an off-road or camping expedition where permanent fixtures are not available and there is no room within the vehicle for a toilet facility.

For those vehicles with sufficient room for a fixed toilet system, manufacturers have developed composting systems that can be used on vehicles.

The Envirolet composting toilet (see Figure 3) is a self-contained system that is advertised as being suitable for use on small boats (Envirolet 2003) and hence, it could be extrapolated, suitable for motor homes. The large volumes of waste created by coaches and trains over short time periods would appear to preclude the use of this system for trains and coaches.

Figure 3: Envirolet toilet (Envirolet 2003)



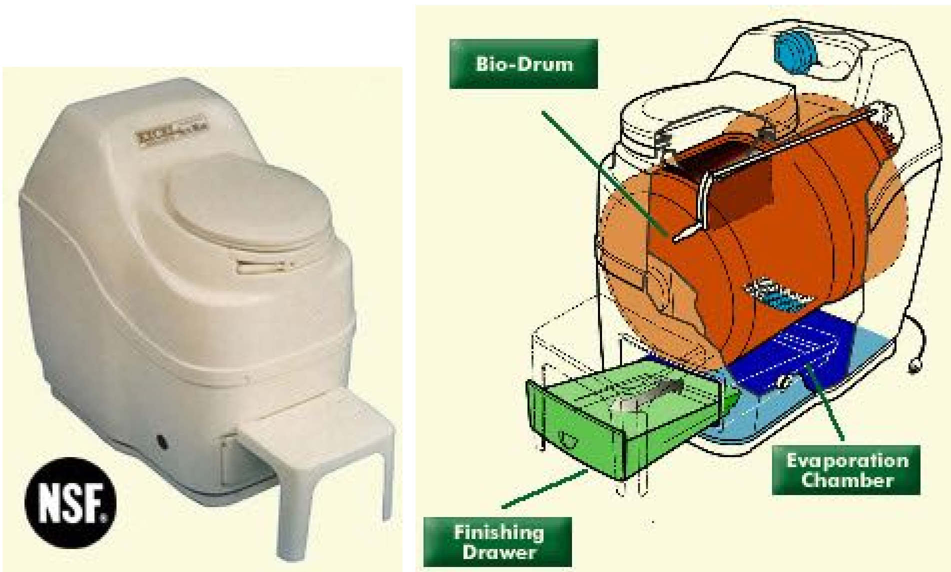
It has a patented automatic six-way aeration and evaporation process with dual fans and an aeration basket that maximises the compost surface area and hence aeration efficiency. Excess liquid is drained to a small holding container. The unit can also incorporate manually-operated mulchers to improve composting to allow the size to be minimised. Table 7 details the Envirolet toilet specifications for use on a boat.

Table 7: Envirolet specifications

Parameter	Specification
Capacity	4 person (holiday) 2 person (continuous)
Dimensions (W x L x H)	635 x 839 x 635 mm
Power requirements	Two 12 V fans (off-shore) Two 12 V fans + 110V optional heater (on-shore)
Maintenance	Addition of aerobic microbes (start-up) Addition of peat moss (periodically)
Compost removal	Annually
Cost	US$1175 (+85 for wind turbine)

The Ecolet composting mobile toilet (see Figure 4) is suitable for use on boats (Aiken and Aiken 1999) and hence also motor homes. Waste is dropped into the Bio-drum which contains a mix of soil, peat moss and water. It is insulated to hold heat and turned occasionally to mix and aerate contents; the hatch automatically closes during turning. After composting, the Bio-drum contents are gravity fed into a finishing chamber where drying air is circulated and the contents thoroughly dried. The finishing chamber is manually emptied of the final odourless product whenever more compost from the 1st chamber is ready for transfer.

Figure 4: Ecolet toilet (Sun-Mar Composting Toilets 2002)



An evaporation chamber collects excess liquid and evaporates it with the help of a heating element whilst a fan continuously removes air from the chamber and discharges it through a vent stack. A filter containing both a zeolite and activated carbon in the fan box absorbs ammonia and organic smells. Table 8 details the Ecolet toilet specifications for use on a boat.

Table 8: Ecolet specifications

Parameter	Specification
Capacity	3 - 4 person (weekend) 2 person (continuous)
Dimensions (W x L x H)	500 x 580 x 740 mm with 300 mm clearance to pull 2nd chamber drawer out
Power requirements	110V heating element, 12V fan
Maintenance	Addition of 6 L peat moss, 1 L topsoil, warm water to moisten (start-up) Addition of 1 cup peat moss (solid waste deposited) Rotate drum 4 to 6 times (every 3rd day)
Compost removal	Every 8 weeks
Cost	US$999 (not including stack)

The SAWI biocom bark chip toilet (see Figure 5) uses dried bark chips as a bulking agent to ensure that operation is odour free. There is an additional advantage in using bark chips in that a bactericidal effect occurs through a constituent in the bark. The SAWI toilet solid and liquid wastes are kept in separate containers with solids being retained in the upper compartment and liquid draining to the bottom compartment (Sawi Biocom 2002).

Figure 5: SAWI toilet (Sawi Biocom 2002)

Table 9 details the SAWI toilet specifications for use in a residence. It is possible that this simple system could be adapted for use on boats, trains, coaches and motor homes where frequent discharge is possible. The requirement to add, and therefore store, bark chips may be a disadvantage but it is necessary to minimise odours. The lack of a fan system may not give total odour elimination and hence it is suggested that a necessary modification would be the inclusion of a vented stack or a ventilation unit. Once again, off-vehicle storage is required.

Table 9: SAWI toilet specifications

Parameter	Specification
Capacity	Up to 8 people (12 L liquid, 15 L solids)
Dimensions (W x L x H)	540 x 620 x 460 (not including vent pipe)
Power requirements	None
Maintenance	20 L (3 kg) bark per filling Addition of bark chips after each use
Compost removal	8 days (2 users), 4 days (4 users), 2 days (8 users) Compost requires 1 year storage before garden use
Cost	On application

The SOG Toilet Ventilation Unit (Aussie Traveller 2002) is marketed in Australia as the ecological solution for motor home and caravan toilets as it negates the use of chemicals for odour elimination. The system incorporates a vent, a fan to force ventilation and thus improve aerobic degradation, and an activated carbon filter to remove odours. The German system can be easily retrofitted to existing chemical systems with the filter requiring changing every 18 to 24 months. The SOG system is not intended for use in a static situation as it relies not only on the circulation of air but also on the movement of the vehicle to help break down the waste matter (Wessels 2003). This system could be employed on trains, coaches and boats.

The Enviro Loo (Enviro Options Australia Pty Ltd 2003) is similar to a composting toilet in that it does not require flush water but is different in that it evaporates liquids from the waste, dehydrating them to less than 5% moisture and between 3 and 5% of their original mass. With such low moisture content, no bacterial action is possible; at moisture levels below 25% there is rapid pathogen destruction, no smell and no fly breeding (Esrey 1998). The Enviro Loo works by allowing liquid to travel to the bottom of the Enviro Loo holding tank and solids to be retained on an inclined-tray approximately half way down the holding tank. Evaporation and dehydration are achieved by constant air recirculation through sunlight heating the air within the tank which is made from black polyethylene. Figure 6 shows the Enviro Loo incorporated into a domestic residence.

Table 10 details Enviro Loo specifications for use in a domestic residence.

Figure 6: Enviro Loo (Enviro Options Australia Pty Ltd 2003)

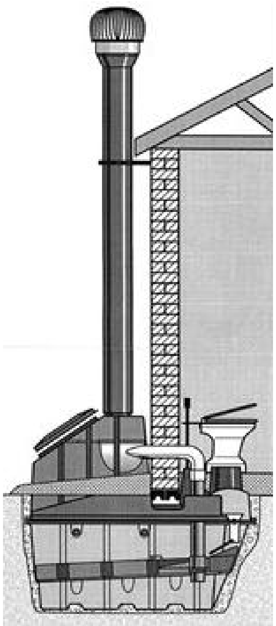


Table 10: Enviro Loo toilet specifications

Parameter	Specification
Capacity	8 – 10 people for 3 uses/d
Dimensions (W x L x H)	System needs adaptation before application as a vehicular system.
Power requirements	None – radiant energy only.
Maintenance	Compost removal can be extended to 4 to 5 years if raking back of solids is undertaken. No bulking agents required.
Compost removal	Every 2 years
Cost	AUD$2660 (incl GST)

It is possible that such a system could be used in a mobile environment. However, since such systems may not be able to guarantee access to sunlight, the power-free nature of operation may need to be sacrificed and a fan and/or heater installed to ensure constant ventilation/ evaporation.

Package Plants

System Basics

Package plants provide complete treatment of unseparated wastewater in-situ. As this necessarily occurs in a small space on boats, trains and motor vehicles, retention times are short as storage volumes are small. Treatment therefore usually involves:

- chemical addition to effect aggressive oxidation of waste;
- high energy input in terms of aeration or heat to allow biological reactions to proceed quickly; and/or
- expensive systems such as membrane filtration if a high quality product is required.

These systems are therefore not very sustainable in terms of the environment, due to both chemical and energy input, or economics as they are expensive in comparison to more natural systems such as composting. In some cases, the cost of water treatment to allow reuse can outweigh cost of fresh water.

In addition, treatment of sewage produces a by-product such as sediment through precipitation, sludge through biological treatment and/or a concentrate through membrane filtration. This by-product requires removal.

High costs of operation and the production of a by-product mean that package plants are suitable only where the cost of fresh water is higher than the cost of renewal. The ‘Type of Package Plants’ section details examples of skid-mounted package plants to show the range of commercially available units for domestic situations. In many cases treatment systems would be tailored to the situation and specifically designed and this is also covered in Type of Package Plants section.

Type of Package Plants

The Equaris biomatter resequencing converter (BMRC) (Equaris 2003) is an American system used for single houses. It combines waste separation, composting and extended aeration to treat both toilet and organic kitchen wastes. As the process is aerobic, odours are reduced. The reactor (Figure 7) is divided horizontally into a top and bottom section; wastes and excess liquid removed from the base of the bed are spread on the top surface. A fan draws air through the composting mass and maintains aerobic conditions. Low-flush toilets are recommended for use in conjunction with the Equaris reactor. Table 11 details the specifications for the Equaris reactor.

Figure 7: The Equaris reactor (Equaris 2003)

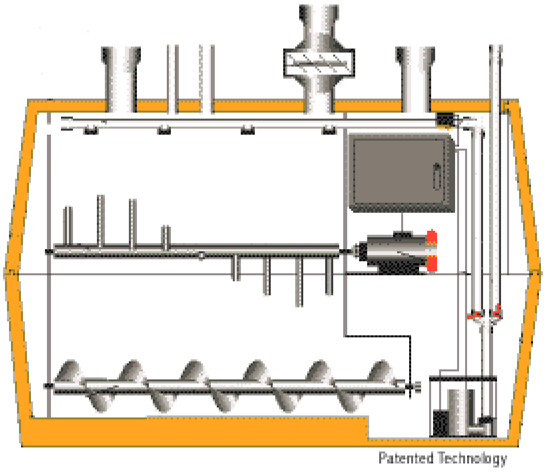


Table 11: Equaris reactor specifications

Parameter	Specification
Capacity	Up to 12 people (full-time)
Dimensions (W x L x H)	1200 x 2200 x 1200 mm
Power requirements	2x gear motors (1.4 amp); 1x fan (27 W); 1x sump pump (1 amp)
Maintenance	4 bales pine bedding, 8 bags potting soil, 9 kg compost starter (start-up), 1 bale pine bedding (monthly)
Compost removal	Annually
Cost	US$7000

A similar system, Eco-logic, is being developed and marketed in Europe for houses that are not connected to the sewer and can accommodate 4 to 5 people. All household sewage water is sent to a buffer tank from where it is pumped to a process tank. The system within this tank has not been fully disclosed but it is claimed to separate the household wastewater after 2 to 5 hours into three layers: clear water that can be reused after UV treatment, unclear (muddy) water that is returned to the buffer tank and sludge that is sent to a separate tank for drying (Tekes 2003).

Randall (2002) proposes an 'all singing all dancing' advanced water treatment system (AWTS) to produce effluent that is equivalent or superior to potable drinking water. The system comprises:

- a solids retention tank,
- a surge/ equalisation tank,
- a filter,
- oxygenation,
- a fixed film bacterial system comprising anoxic, aerobic, anoxic, and aerobic compartments with an internal recycle from the first aerobic zone to the first anoxic zone,
- settlement with sludge returned to the first anoxic zone,
- storage,
- ozonation and UV oxidation to degrade resistant organics,
- ultrafiltration followed by nanofiltration to almost completely remove N and P, and
- UV disinfection.

As previously discussed package treatment systems can be tailor-made to suit available space and the required final effluent quality. Table 12 details some of the unit operations that could be employed within a package treatment system employed on a moving vehicle. Design would proceed with the assumption that water usage would be minimised and that waste consists of urine, faeces and toilet paper, all other waste being placed into a solid waste receptacle. Unit operations would then be selected and placed in sequence to achieve the required final effluent quality. Final (polishing) systems cannot be used effectively without appropriate upstream preliminary, primary and secondary systems.

Table 12: Unit operations for package plant treating unseparated wastewater

Position	Operation	Removal			
		Solids	Organics	Nutrients	Pathogens
Preliminary	Gross solids trap	Gross only	No	No	No
	Screen	Gross only	No	No	No
Primary	Chemical precipitation	High	Med-High	Yes	Low
	Settling	Settleable	Medium	No	Low
	DAF	Settleable	Medium	No	Low
Secondary	Activated sludge Note 1	High	High	If designed	Medium
	Fixed film Note 2	High	High	If designed	Medium
Final (Polishing)	Disinfection Note 3	No	No	No	High
	Chemical addition	Med-High	Medium	P only	No
Note 4	Activated carbon	Med-High	High	Yes	Medium
	Ion exchange	Med-High	If designed	Yes	No
	Filtration (granular)	Med-High	Medium	No	Low
	Ultrafiltration	High	High	No	High
	Reverse osmosis	High	High	Yes	High

NOTES:

1. *There are many different types of activated sludge systems including sequencing batch reactors (SBR), continuous reactors, oxygen-activated systems, extended aeration and various nutrient removal arrangements. Some of these systems require downstream solids settlement to remove solids and some require the sludge to be returned.*
2. *There are many different types of fixed film systems including submerged systems, rotating biological contactors (RBC), roughing systems, different medias and conventional systems. Some of these systems require downstream solids settlement to remove solids.*
3. *Disinfection includes chemical addition and UV irradiation.*
4. *Many of the polishing systems, especially the membrane processes, require high quality influent wastewater and hence may require an upstream unit such as a granular filter*

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Low Flush / Vacuum Toilet

Vacuum toilets are used widely in ships, aeroplanes and trains and are usually connected to a holding tank. The requirement for water is only for rinsing the bowl and is usually approximately 0.25 to 0.5 L/flush in volume (Evac 2002), less than 5% of the volume used by conventional low-flush toilets. Often the rinse water has chemical added for disinfection and odour minimisation and there may be some associated noise with the use of a vacuum.

In contrast to conventional gravity toilets where the energy for transport is supplied by the kinetic energy of the flushing water, vacuum toilets consume electricity for the vacuum and wastewater pumps. Studies of vacuum toilets used within a German apartment building showed a per capita energy usage of 26.6 kWh/y (Herrmann and Hesse 2002). In addition the installation costs were shown to be about 3 times that for a conventional flush toilet system. This higher than usual energy and capital cost for a toilet system combined with the requirement for chemical addition mean that vacuum toilets are usually not considered to be environmentally or economically sustainable.

Low flush or microflush toilets (see Figure 8) operate on 2 L of water at a pressure of 20 to 50 PSI and air at a pressure of 60 to 65 PSI (Microphor 2002).

Single toilet systems in use on vehicles should incorporate no- or micro/low-flush toilets.

Figure 8: Microphor rail waste system (Microphor 2002)

Incineration Toilet

'Incinerating toilets are self-contained units consisting of a traditional commode-type seat connected to a holding tank and a gas-fired or electric heating system to incinerate waste products deposited in the holding tank. The incineration products are primarily water and a fine, non-hazardous ash that can be disposed of easily and without infection hazard' (US EPA 1999).

The incineration toilet does not require flush water, is relatively odourless and produces as little as one teaspoon of ash per use. However it requires energy, resulting in higher than average costs for users, and it is not entirely pollution free through some air pollution and the frequent use of anti-foam agents to prevent boil over of liquid waste and catalysts to aid incineration. Wastes are collected in a sealable chamber of stainless steel or cast nickel alloy. Vapour and products of combustion are fed by blower fan to a venting system which may be as simple as an exhaust pipe or may incorporate an afterburner or other odour control system. Some units cannot be used during an incineration cycle.

Incineration toilets can be designed to incinerate waste from a single use or they may be designed to store waste for incineration after 40 to 60 uses. The former could be used in small boats and motor homes whilst the latter would be applicable for use on coaches and trains where waste volumes and usage are considerable higher. Maintenance involves regular emptying of the ash collection pan and cleaning of the burner and combustion chamber every 90 days. A mobile incineration toilet installed in a van, and available for hire in Japan, requires weekly removal of ashes (Rama Robots 2000). Power to this toilet is supplied by a dynamo (100 V 25A 2.5 KVA).

Incinerator toilets cost from US$800 to US$1500 including electric wiring and a fireproof vent for the waste gases. In addition, there are some replacement costs for component parts. The average energy use is 1 kWh/ flush (University of Minnesota 2002) which is a very high energy consumption and could easily translate to around 700 – 1000 kWh/y.capita.

Gas combustion toilets can be used where there is an absence of electricity (e.g. boats and caravans). Gasaloo (EH Cambridge & Co. 2000) is an Australian proprietary skid-mounted system available commercially (see Figure 9). Table 13 details the specifications for the Gasaloo.

Figure 9: Gasaloo (EH Cambridge & Co. 2000)

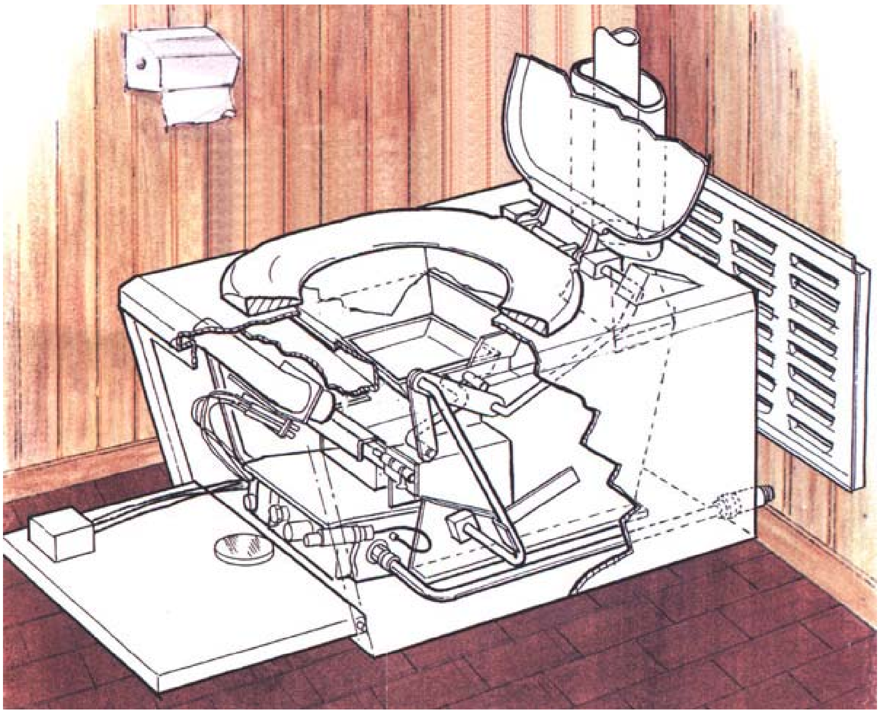


Table 13: Gasaloo reactor specifications

Parameter	Specification
Capacity	6 people daily
Dimensions (W x L x H)	435 x 765 x 450 mm
Power requirements	80 g propane/ use
Maintenance	2x 45 kg gas cylinders 9V battery for electronic control
Ash removal	Weekly
Cost (1999)	NZ$3500

Chemical Treatment

System Basics

Chemicals are added to wastewater collected from mobile toilets for a number of reasons:

- to oxidise or breakdown organic pollutants;
- to precipitate solids;
- to disinfect and kill pathogenic bacteria; and/ or
- to minimise nuisance odours.

Chemical addition is not environmentally sustainable, may be expensive and has certainly become less socially acceptable over the past decade.

The capital cost of chemical toilets varies greatly depending on the model and size and may range from US$200 to $700 plus installation (University of Minnesota 2002). Costs of the chemical used may be in the range of 2 to 3 US cents/flush.

Types of Chemicals

There are many types of chemical that are added to wastewater from mobile toilets; the most commonly used are proprietary chemicals that come already prepared and contain deodorants, disinfectants and perhaps colouring agents. Table 14 summarises some of the chemicals that are currently commercially available and includes a 'home-made' mixture.

Table 14: Commercially available chemicals for wastewater treatment

Name	Action					Comments	Reference
	Biocide	**Odour control**	**Bowl cleaner**	**Colour added**	**Corrosion inhibitor**		
Formaldehyde	X	X	-	-	-	Inexpensive but carcinogenic and not biodegradable. Not recommended for use.	
'Home-made'	X	X	-	-	-	5 L water, 250g powdered borax, 600 mL cloudy ammonia, 1 L concentrated disinfectant. Apply 250 mL/80 L holding tank. Inexpensive alternative.	(Gray 2000)
Super Kem Blue	X	X	-	X	-	Aqua-Kem Blue/ Green is in concentrated form and Dri-Kem is in granular form.	(Fiamma 2002)
Super Rinse Pink	X	-	X	X	-		(Fiamma 2002)
TCEG-1000	X	X	-	X	X	Odour control through masking fragrance. Ethylene glycol for freeze protection.	(Additives Inc. 2002)
TCDP-100/ TCL - 100	X	X	-	X	-	Odour control through masking fragrance. Used by railroads, buses, airlines.	(Additives Inc. 2002)
TCMC-1000	X	-	-	-	X	Magnesium chloride based.	(Additives Inc. 2002)
TCPG-1000	X	X	-	X	X	Odour control though masking fragrance. Propylene glycol for freeze protection.	(Additives Inc. 2002)

Some additive products contain enzymes and/or live bacteria. If these are to be used, the location of the wastewater holding tank needs to be considered because high temperatures, such as those experienced near the vehicle engine will kill bacteria. The efficiency of enzymes is also reduced at low temperatures, so vehicles being used in winter months or in cold climates need to ensure that the wastewater holding tank is insulated and/or heated.

A different type of additive is SBG-1 (URinBiz.com 2002). This is a super absorbent non-hazardous sodium salt of polyacrylic acid that can absorb up to 1000 times its weight in liquid, depending on the acidity and temperature of the liquid. SBG-1, which contains a fragrance, solidifies into a gel with the addition of liquid. Its suggested use is in conjunction with a portable commode comprising a moulded plastic toilet seat, a 12 to 20 L bucket and a liner bag. Between 90 and 120 g (80 g/ 4 L) of SBG-1 and 5 cm water is placed in the liner bag for overnight use allowing up to 7.5 L of urine to remain odourless and solid. SBG-1 absorbs the liquid in faeces but additional water may be needed to cover faeces for complete odour control. The solidified contents can be flushed down a toilet or disposed of to landfill. The cost of a system is $34.45 US for the bucket, seat, 240 g SBG-1 and liner (URinBiz.com 2002).

The Australian invented AutoSan (Marine Direct 2002) is a chlorine dosage system which is used in conjunction with a macerator. Liquid pool chlorine (10% NaOCl) is used at a rate of 8mL/1.5L waste and treatment takes 5 minutes. The system is also designed to be failsafe with respect to both treatment and accidental pump out.

Holding Tanks

There are many different proprietary holding tanks commercially available; they are usually marketed as mobile toilets complete with freshwater and wastewater holding tanks and use a self-priming hand pump to flush and evacuate wastewater (Jabsco 2002; Raritan 2002). Chemicals, as summarised in Table 14, are usually added to the holding tank to break down waste matter, prevent clogging, prevent deposits sticking and to eliminate odours. Chemicals can also be added to the freshwater holding tank to keep flush water fresh and to aid with downstream transport and storage.

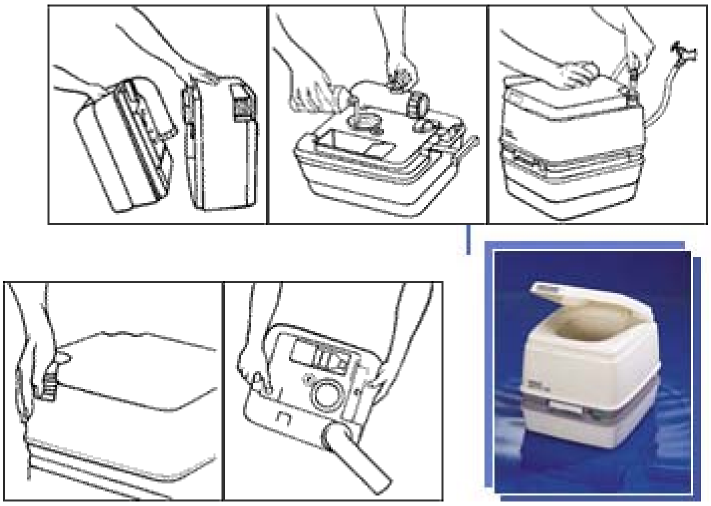
Larger vehicles such as trains and larger boats will usually have a specifically designed and fabricated holding tank but smaller vessels may incorporate a proprietary system. A 23 L holding tank is recommended for small craft and overnighters (Jabsco 2002); this would appear to be on the small side even if the lower figure of 3L per flush is taken from Table 2 (Chapter 2), but is backed up by commercial system details (Table 15) and thus suggests that campervan flush volumes are much less and probably in the order of 0.3-0.5 L. The holding tank is usually manually removed and emptied as shown in Figure 10.

Table 15: Details of proprietary holding tanks

Name	Size (WDH) mm	Comments	Reference
Thetford portable toilet	379 x 419 x 338	Can add battery operated electric pump for flushing	(Thetford 2002)
Fiamma bi-pot	435 x 360 x 330/382[NOTE]	13 or 20 L capacity	(Fiamma 2002)
Porta potti 335	381 x 343 x 304	27 average flushes, 10 L freshwater, 10L holding tank capacity	(Fiamma 2002)
Porta potti 345	412 x 381 x 330	32 average flushes, 14 L freshwater, 11 L holding tank capacity	(Fiamma 2002)
Porta potti 365	412 x 381 x 413	57 average flushes, 14 L fresh water, 21 holding tank capacity	(Fiamma 2002)

NOTE: For 13 and 20 L capacity respectively.

Figure 10: Operation of Thetford portable toilet (Thetford 2002)

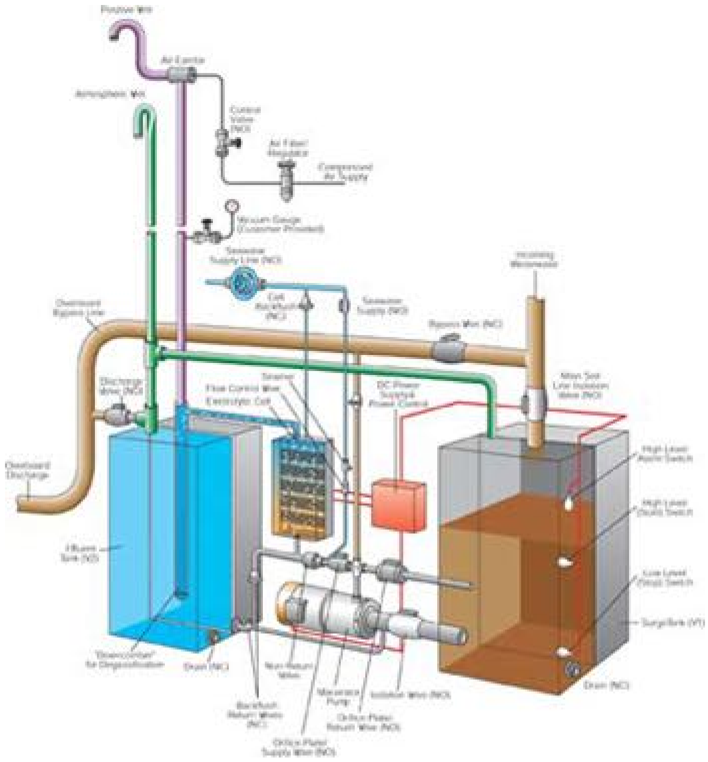


Treatment Using Sea Water

There are a number of systems available for boats operating in seawater that essentially use the sodium chloride (NaCl) readily available in the sea water.

The Omnipure system (Severn Trent De Nora 2003) collects incoming wastewater in surge tank until a high level is reached. At this stage, macerators grind solids within the wastewater down to 1.5 mm, sea water is electrolysed to produce sodium hypochlorite (NaOCl) and then mixed with the wastewater resulting in the rapid oxidation of 90 to 95% of the sewage. A total bacterial kill is also achieved. Treated wastewater is stored for 30 minutes prior to discharge. The system is shown in Figure 11.

Figure 11: The Omnipure system (Severn Trent De Nora 2003)



Using sea water for oxidation and disinfection has the following advantages:

- there are no chemicals added thus increasing environmental sustainability;
- there is no need for chemical storage and hence volume requirements are reduced;
- the treatment[8] is completed in approximately 30 minutes (biological systems usually require over 6 hours); and
- there is no bacterial colony to maintain and hence shock loads will not affect the unit and parameters such as pH and temperature do not need careful monitoring.

Table 16 summarises the details of the base (6MR) Omnipore unit.

Table 16: Details of Omnipure system

Parameter	Specification
Capacity	2960 L/d (1.6 kg BOD/d)
Dimensions (W x L x H)	914 x 635 x 610 mm
Power requirements	10 KVA (equivalent 10kW)
Maintenance	General wear and tear
Cost	On application

Pepcon Systems (1999) offer a similar system with an anode operating at a low DC voltage. They specify power requirements as 5.0 to 6.0 kWh/kg NaOCl depending on the salt content and temperature of the seawater.

The Lectra/San (Raritan 2002), a popular US system used on boats (see Figure 12), is a two chamber system:

- the first contains a macerator and electrodes to convert seawater to hypochlorous acid for oxidation and disinfection; and
- the second contains a mixer and electrode.

Treated waste from the second chamber is discharged overboard or into a holding tank. Flush water is taken directly from the surrounding waters.

8 NaOCl is a powerful chemical oxidant which will oxidise the complex compounds ($C_xH_yO_z$) in the wastewater to final products such as carbon dioxide (CO_2) and water (H_2O). It is the same active compound as is produced in the application of chlorine (Cl_2) in water.

Figure 12: Lectra/ San system (Raritan 2002)

Aqua-san (AMI 2002) is the Australian version of Lectra/San. In freshwater, the system is called Purasan and requires addition of salt through a tablet cartridge dispenser. Table 17 summarises the details of the saltwater unit.

Table 17: Details of Lectra/ San system

Parameter	Specification
Capacity	8 – 10 people
Dimensions (mm)	Kill tank 25 L (400 dia x 255 length) Holding tank 70 L (400 dia x 600 length)
Power requirements	12, 24 or 32 depending on pump types
Maintenance	General wear and tear
Cost	Lectra/ San $1100 US, salt feed tank and pump $300

Oil Recirculating Toilets

Oil recirculating toilets (US EPA 1999) replace flush water with mineral oil or another similarly non-aqueous medium. The water-based urine and the solid waste products are separated from the oil medium which is then filtered and recycled to the toilet. The waste is separated and held in a tank for disposal at an approved facility.

These systems are not common and have many disadvantages, including the incomplete separation of wastes from the oil and vice versa, and are therefore not discussed further in this document.

Critical Comparison of Existing Systems

The systems discussed in this chapter and deemed applicable for use as a single toilet system are critically compared in Table 18. It is assumed that low flush toilets or toilets utilising vacuum systems will be used when there is a requirement for flush water, as this is important for both sustainability and for minimising storage requirements.

The most environmentally, and potentially economically, sustainable system would be that which did not require flush water and therefore had no requirement for treatment and recycle of wastewater. This assumes that there is no associated hand basin with the toilet and that hand cleansing is done by means of moist towelettes which can be disposed of separately or, in some cases, to the toilet. Such a system negates the need for fresh water storage completely and this is highly advantageous on most passenger vehicles.

A further advantage of systems that do not require flush water is the compact nature of the waste requiring final disposal. Composting systems comply with these criteria but would not be applicable to larger vehicles such as trains and coaches unless they were able to be regularly emptied and an off-vehicle storage area available.

Incineration toilets also comply but are expensive with respect to energy usage.

Table 18: Comparison of common single toilet treatment systems

	Chemical/ holding tank	Composting	Package plant	Incineration	Sea Water
Applicability					
Boat (<6 passengers)	Current	Current	Not economic	Potential	Current
Boat (6-20 passengers)	Current	Unit too small	Potential	Potential	Current
Coach	Current	Unit too small	Potential	Potential	Not applic.
Motor home	Current	Potential	Not economic	Potential	Not applic.
Train	Current	Unit too small	Current	Potential	Not applic.
Inputs					
Water	Low	Nil	Low	Nil	Surrounding waters
Energy	Nil	Medium	Medium	High	High
Chemical	High	Nil	Nil - Low	Low	Nil
Final products					
Water – reuse	No	N/A	Potentially	N/A	N/A
Solid–fertiliser	No	Yes	No	No	No
Urine-fertiliser	No	No	No	No	No
Social acceptability	Medium	Low - medium	Medium - high	Low - medium	Medium
Commercial systems					
Example (≤ 6 pax)	Various	Envirolet Ecolet	Equaris (domestic)	Gasaloo	Lectra/San
Cost Note 1 ($Aus 2003)	280 - 970	1700 1390	9720	3400	1530
Note	2	3, 4	5	-	-

NOTES

1. *All costs have been converted to 2003 Australian dollars using exchange rates current in December 2003. They are indicative only of the main item and do not include add-ons such as stacks.*
2. *Chemicals are added to achieve oxidation of organics, odour suppression, corrosion inhibition and/ or bacterial disinfection. Chemicals are placed in the flush water and/ or in the wastewater holding tank.*
3. *It is assumed that:*
   - *urine is separated and/ or evaporated within system so that the need for the addition of bulking agent by user is eliminated;*
   - *the operator maintains the system through addition of bulking agent before/ after journey;*
   - *compost removal requirements less than 3 monthly; and*
   - *a containment and ventilation system is used to prevent odour nuisance.*
4. *There is potential for composting systems to be used for large operations where off-vehicle storage exists.*
5. *It is assumed that:*
   - *the system has been tailored to allow final effluent criteria to be met;*
   - *biological treatment through either a fixed film or suspended growth process is incorporated; and*
   - *the system is fully enclosed so that odours and the risk of public access are eliminated.*

Composting systems are therefore environmentally preferable to incinerating toilets on the basis of the large amount of energy required for the latter. However there is a poor social acceptance of composting toilets which may need to be overcome by improved design. Users should be unaware of the fact that the toilet utilises composting technology[9] and this could be achieved by eliminating odours and preventing the user from seeing the compost pile.

[9] Users would however need to be educated with respect to the type of materials that could be disposed of into the toilet such that its operation was not compromised.

Chapter 4

Innovations

Introduction

This chapter describes and summarises innovative technologies that may be applicable to the single toilet system for application on vehicles.

Urine Separation

Current research in Northern Europe (Fittschen et al. 1997, 1998; Hanaeus et al. 1997; Hoglund et al. 1998), Germany (Otterpohl et al. 1999) and Switzerland (Larsen et al. 1997) has been concerned with separation of urine and faeces in order to tailor treatment requirements. Urine contains a high proportion of wastewater nutrients (see Table 5) and hence, if separated, can be reused to allow nutrient recycle[10]. Currently 2000 separating toilets have been installed mostly in eco-villages and are being monitored in Sweden. They incorporate:

- a specially designed separation toilet (see Figure 13);
- urine collection (urine accounts for approximately 1% of total wastewater flow (Johansson and Nykvist 2001) and storage for 6 months to reduce pathogenic bacteria prior to direct use in agriculture; and
- treatment of faeces by dry composting system or in combination with greywater in traditional systems.

Figure 13: Urine separation toilet (BB Innovation 2002)

Urine separating toilets have two separate bowls: one in the front for urine collection and one at the back for faeces. The bowls vary in size and style with different manufacturers. Only a small quantity of water is used to flush the urine bowl; faeces are flushed to a sewage treatment works or composted with no flush at all. Urine separation toilets can save from 5 to 40 L/person.d of flush water depending on individual habits and the type of toilet (Johansson and Nykvist 2001). Larsen et al. (2001) found that the amount of flush water was reduced by up to 80% and in terms of the single toilet system; this would mean that lower flush water storage volumes would be required on vehicles.

A level of user education is required for the system to function successfully. Most of the toilets require men to sit; some only open the urine drain through pressure on the seat (Otterpohl et al. 2002) thus saving flush water. Toilet paper is placed in the faeces section for composting or to a separate bin depending on the type of

[10] The fertilising effect of urine is close to that for chemical fertiliser (90% N, 100% P) (Jonsson 2001) and therefore can be used as a substitute.

composting system utilised. Toilets can also be adapted for use by small children through a second lid with a smaller hole (Esry 1998).

Commercially available toilets include the Gustavsberg separation toilet (Berger Biotechnik GmbH 2002) and the Dubbletten (BB Innovation 2002).

The urine collection system is usually ceramic with a hydrophobic nano-coating and a capacity of 1.5 to 2.5 L/person.d (Johansson and Nykvist 2001) or at least 6 months storage (Li et al. 2001). Other considerations with respect to the urine storage system include:

- the absence of metals in the system as urine is very corrosive;
- pipe collection of urine should not be ventilated and thus the total ammonia emission (collection, transport and storage) is <1%;
- acid can be added to stabilise ammonium; lowering the pH value of urine will prevent the release of N to the atmosphere (Schonborn 2002);
- storage tanks should be filled from the bottom;
- 76% of stoppages in the U-bend of the toilet are due to the precipitation of calcium and magnesium ammonium phosphates on hairs and fibres. (Jonsson 2001; Vestgard 2002) therefore regular (6 monthly) cleaning with a mechanical snake or caustic soda is required;
- 24% of stoppages are due to precipitation on the pipe wall and this must also be cleared with caustic soda every 6 months or so; and
- generally stoppages can be avoided if there is at least a 1% fall in the piping and a diameter greater than 50 mm (Vestgard 2002).

After 6 months storage at 20ºC, the urine can be used as fertiliser (Vestgard 2002). Concentrated urine should be diluted 1 part urine to 8 parts water when spreading on vegetation and distribution must not take place closer than 100 m from a source of water supply, or 50 m from a watercourse in order to avoid contamination. It is important to store urine in air-tight containers so as to prevent odours and loss of nitrogen to the air.

The Separett Villa Ecological Toilet (Ecovita 2004) appears to be quite applicable to usage on smaller vehicles. Faeces are stored in a bucket within the unit (see Figure 14) and can be readily removed, for disposal or further treatment, when necessary. It uses no flush water, requires a separate urine storage system and a fan/ vent system. The fan can be powered a 12 V battery.

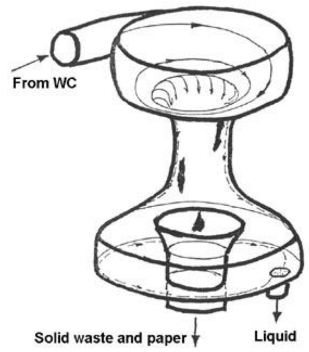
Figure 14: The Separett Villa Ecological Toilet (Ecovita 2004)

However, for urine separation to work it is necessary to gain social acceptance. Focus groups have showed (Pahl-Wostl et al. 2002) that the system must offer the same level of comfort and not be more expensive than conventional technologies. The attitude was found to be generally positive in Scandinavian countries but is yet to be tried in Australia. In terms of use on vehicles, it is recommended that the system be used to reduce water usage and allow composting of faeces. Urine may still need to be disposed of to a specific discharge point or evaporated as there is no legislation in Australia that relates to the direct use of urine in agriculture.

Faeces / Flushwater Separation

A commercial system, the Aquatron (see Figure 15), can be used to separate faeces from flushwater. It uses a combination of a whirlpool effect, gravitation and surface tension. There are no moving parts and no need for chemicals; the system is constructed from a single plastic piece.

Figure 15: The Aquatron (Vinneras and Jonsson 2002)



'Water follows the outer surface of a vertical, hourglass-shaped separator across the waist and further along the expanding outer surface of the lower section, while larger particles drop straight down from the waist by gravitation. Thus two fractions, separated water and separated solids are formed.' (Vinneras and Jonsson 2002) Since the urine has been contaminated with pathogens through contact with faeces, it is more problematic to treat and discharge than urine separated in a urine separation toilet.

Separated solids (paper and faeces) can be composted and separated water treated independently. Toilet paper can entrain water and hence there is a drain from the solid compartment to the separated liquid in order to keep the compost dry. This will increase the contamination in the separated liquid and will need to taken into account if water is to be reused.

The Aquatron separator costs €508 (BB Innovation 2002). The unit is 500 mm high and has a 360 mm diameter. It can be used with standard toilets or with urine separation toilets although flush water from the latter is low and is much easier to separate and/or evaporate from a composting system.

A Swedish company (Tekes 2003) has developed a system that could be placed downstream of an Aquatron. The system is for the treatment of urine and faeces flush water and incorporates ultrafiltration, ion exchange and UV disinfection. Particles down to a size of 1 micron are removed and the water is completely free of bacteria and parasites. This level of treatment allows water to be treated to the standard of drinking water and hence to be reused. Faeces would be composted separately.

Membrane Technology

System Basics

Membrane systems allow wastewater to be treated to a high quality as they utilise membranes with apertures smaller than most pollutant molecules, bacteria and even nutrients. They work by the application of a differential pressure which forces treated wastewater across the membrane and retains pollutants in the retentate. The capital and operating (energy and membrane replacement) costs are high in comparison to other systems.

However, membranes have 'come down in price by more than 70 percent over 10 years and demonstrate reduced fouling and operational costs' (Garman 2003). This means that they are far more accessible for wastewater treatment in terms of cost and maintenance requirements.

The use of membrane systems in high-rise buildings in Japan to allow for the reuse of water to flush toilets is well established (Randall 2002). These systems produce recycled water with an average quality of 0.5 mg/L BOD, less than 1 mg/L SS, 0.3 mg/L NH_4-N, 31 mg/L NO_3-N and no detectable bacteria (Mitsubishi Kakoki Kaisha Ltd 2003). A typical system includes:

- primary and secondary screens (the secondary is necessary to remove fines that may clog the ultrafiltration unit);
- contact oxidation with high sludge age to reduce sludge wastage amounts;
- cross-flow ultrafiltration, with chemical backwash returned to the activated sludge system, to remove colloidal particles, micro-organisms and any undecomposed matter;
- activated carbon adsorption for colour removal; and
- chlorine disinfection.

Membrane technology has been used successfully at large events. Continuous microfiltration (CMF) to 0.2 µm followed by reverse osmosis (RO) was used to recycle wastewater and rainwater runoff for toilet flushing and irrigation at the Sydney Olympic Games (Rogge 2000).

Direct ultrafiltration (DUF) of domestic wastewater has been trialled (Evenblij et al. 2002) and found to produce a mixture of water and nutrients that is free from solids, bacteria and viruses but still high in COD (200 mg/L), nitrogen (44 mg/L) and phosphorus (5 mg/L) . This permeate is thought to be very useful for crop fertilisation and irrigation. It was found that steady state could be achieved using production times of 10 minutes and a 1 minute backflush and a trans-membrane pressure of 0.2 to 0.4 bar.

Otterpohl et al. (2002) recommends black water undergoes solid-liquid separation, perhaps by the use of an Aquatron, followed by membrane technology for the liquid to allow reuse of flushwater and anaerobic decomposition of solids to provide fertiliser and energy. This system is feasible but the cost of liquid treatment is still comparatively high.

Multiple Water Reuse

Multiple Water Reuse (MWR) systems provide localised treatment of wastewater and reuse of the treated water for domestic, commercial and industrial purposes. MWR treats raw sewage using microfiltration and reverse osmosis[11] (RO) to produce a product as detailed in Table 19. There is no biological treatment within the system and hence aeration is required for cleaning purposes only. RO should remove all bacteria and pathogens but this can be augmented with chlorination or UV if necessary. Pilot-scale MWR systems produces 100 kL/d of treated water and fit into two 6 m standard shipping containers (Anonymous 2002) hence this type of set up is therefore far too large for vehicle systems. It could potentially be applied to smaller flows but whether this could be done economically is unclear. MWR does have some disadvantages as it does not remove all soluble BOD or COD and is prone to membrane fouling (Henderson 2003). It also generates a concentrated retentate stream, which will need to be stored, treated and/or disposed of separately.

Table 19: MWR effluent quality (Anonymous 2002)

Parameter (mg/L)	Screened	Microfiltration	Reverse Osmosis
BOD	230	89	<2
TOC	103	46	0.6
SS	144	<2	
TDS		403	12
TKN	50	51	5.5
Total P	11.2	9.0	0.03
Faecal Coliforms (cfu/100 mL)	5.1×10^6	1.3	<0.1

Membrane Bio-reactors

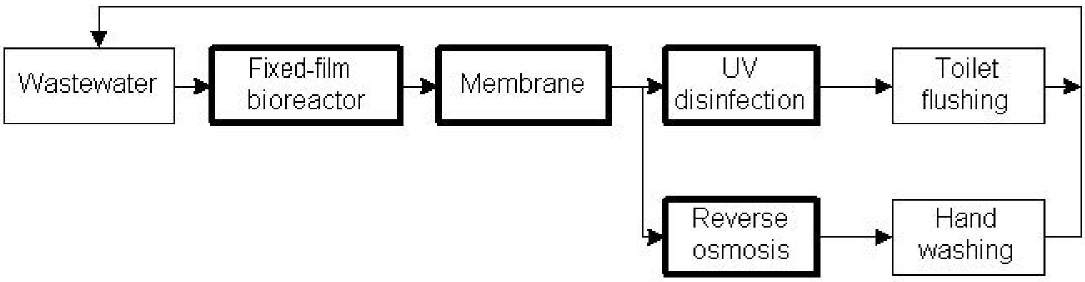
Membrane bio-reactors (MBR's) utilise aerobic biological treatment to treat wastewater. Whereas conventional systems utilise a biological reactor and a settling unit, MBRs replace the settling unit with membrane filtration. Whilst significantly reducing treatment plant volume, this also provides advanced treatment for coliform bacteria and solids which are not removed completely by conventional processes. The levels of BOD removing biomass (sludge) maintained in an MBR system are high in comparison to conventional systems and therefore the unit size and sludge production are minimised. Limitations of MBR include fouling problems and subsequent increase of long-term operational costs, and the requirement for additional treatment units for removal of nutrients.

MBR fouling problems have been reduced with the use of submerged hollow-fibre (HF) membranes with air bubbling. The use of intermittent aeration to prevent fouling increases the amount of nitrogen removed by the system as it allows simultaneous nitrification and denitrification. Such a system has been reported to last up to 250 d without chemical cleaning or backwashing (Yeom et al. 1999). Using an 8 to 15 h HRT and very long SRT (4 to 5 months) gives 96% TCOD, 100% SS, and 83% TN removal (Yeom et al. 1999).

QinetiQ, the commercial arm of UK defence research agency, have developed the Intratech Water Processing System (IWPS) that incorporates membrane treatment; it appears to be similar to the MBR in its conception. The IWPS (see Figure 16) is used on trains for wastewater treatment. Sludge is removed from the bioreactor every 30 d and all water is reused. The system is awaiting certification by the relevant European bodies before its launch (Clarke 2002).

[11] Reverse osmosis provides the highest separation available through membrane technology, removing not only all bacteria but also nutrients.

Figure 16: IWPS system



Vermiculture

Organic materials including sewage sludge can be fed to a variety of worm species in order to break the material down and render it harmless and suitable for use as a plant growth medium and soil conditioner. This system is called vermiculture.

The worm colonies need a wide range of organic materials including carbonaceous materials such as paper and cardboard, blended with other organic materials such as vegetable food scraps. Vermiculture therefore may not be as suited for use as a single toilet system since the colonies cannot survive on sewage sludge alone.

Additionally, the Vermiculture system treats only the solid portion of the wastewater. Liquids are drained through the organic biomass and therefore require separate treatment or storage prior to discharge. Strategies similar to those discussed with respect to urine separation could be used to handle the liquid waste stream should vermiculture be viable as a system for use on vehicles such as motor homes where a variety of organic wastes are available.

Electroflocculation

Electroflocculation is the process whereby coagulating metal ions are electrically added to wastewater. These ions produced by the anode, coagulate the pollution in the wastewater and the coagulated pollutants are removed by the hydrogen bubbles generated at the cathode during the process. Recent innovations with respect to element failure have made the process more economic, however it does not appear to have been trialled at full-scale. Pilot-scale units have shown oil and grease removal rates in excess of 99.95% and bacterial removal rates in excess of 99% (Robinson 2000); low sludge formation has also been observed.

The process therefore appears to have a number of advantages:

- a one-step process whereby pollutants are both coagulated and removed;
- no requirement for chemical addition albeit at a high energy cost; and
- low by-product formation.

Typical process times appear to be between one and three hours (Robinson 2000). This system is not fully developed enough for utilisation and would require further detailed research before application. The development of technology should be monitored however as it is promising with respect to utilisation as a single toilet system on vehicles.

Distillation

A vapour compression distillation system that delivers 50 to 75 L/h of pure distilled water has recently been developed and marked by Ovation Products (Ovation Products 2003). Distillation[12] of small flows is prohibitively expensive but Ovation Products claim to have reduced the costs such that they are comparable to reverse osmosis but with the added benefit that all of the water is recouped. The unit's dimensions are 380 diameter x 800 mm high and it requires a 120V, 20A, 60 Hz, single phase power supply. Efficiency of the unit is quoted as 35 kWh/3800 L (1000 US gal) (Ovation Products 2003).

The system has primarily been developed for industrial wastewater but research is currently exploring application with respect to septic tanks (Lockwood 2003). It is easy to envisage that such a system could be utilised with biologically treated wastewater to allow for almost total reuse of flush water. Once again the technology should be monitored with a view to application as a single toilet system for vehicles should it become proven and economically applicable.

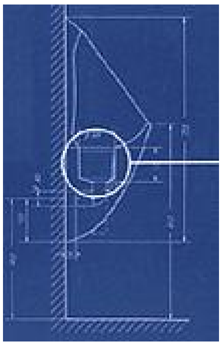
[12] Distillation effectively separates all impurities including pathogens and inorganic contaminants from water, and delivers a pure product. The remaining fraction would be highly concentrated.

Waterless Urinal

A US company has developed a waterless urinal (Anonymous 2003) that operates by the use of a patented cartridge. The device is in use in India and on high-speed Shinkansen trains in Japan.

The cartridge is made from recyclable ABS, is easy to install and replace and has an average life cycle of 7000 uses[13]. Its positioning with respect to the urinal is shown in Figure 17.

Figure 17: Waterless urinal showing cartridge position (Falcon Waterfree Technologies 2003)



The cartridge serves four purposes:

- to funnel liquid from the bowl;
- to eliminate odours by creating a barrier between the urine and the open air through the use of a low density, biodegradable sealant liquid;
- to filter out uric sediment; and
- to allow remaining urine to be freely disposed of.

An interesting speculation would be the use of such a cartridge with a urine separating toilet; this would ensure efficient urine drainage and eliminate odours.

Odour Removal

Odour removal/ elimination forms an important facet of any single toilet system used on a vehicle. Obviously the first course of action is correct design in the prevention of odour formation or containing/ collecting/ discharging any unavoidable odours without causing odour nuisance. These odours can be directly discharged through a vent or may be treated prior to discharge, for example by passage through an activated carbon filter, if there is any likelihood of odour nuisance. Activated carbon is a well proven method of odour treatment but has the disadvantage that the carbon becomes exhausted after a certain amount of usage and thus requires either regeneration or replacement.

An innovative method uses highly ionised air, achieved by use of ion tubes and alternating current, which can disassociate different types of gaseous compounds. (Van Durme and Tulenko 2003) Odorous chemical compounds such as hydrogen sulphide, dimethyl disulfide, and ammonia are oxidised to form benign end products such as carbon dioxide, water vapour and nitrogen. The process, trade name Bentax, has been used in conjunction with ventilation systems to treat inlet air and hence maintain air quality within potentially odorous spaces. It is possible that it could be adapted for use with single toilet systems but has the disadvantage of high capital and operating (energy) costs.

Hand basin toilet

A simple way of reducing the volume of water used in toilet facilities is through the use of a 'hand basin toilet' (see Figure 18). These systems are popular in Japan being installed for both domestic and commercial applications.

[13] The pressure drop across the cartridge increases with each use and hence the cartridge needs to be replaced when a decrease in the speed of drainage is noticed.

Figure 18: Japanese hand basin toilet (CSBE 2000)

The hand basin toilet incorporates a hand basin at the top of the cistern with a tap for hand washing. The tap operates automatically when the toilet is flushed to simultaneously refill the cistern and allow hand washing (without soap).

Critical Comparison of Innovations

Those systems discussed in this chapter and deemed applicable for use either as a single toilet system or treatment for wastewater are critically compared in Table 20 and Table 21 respectively.

The comparison in Table 21 assumes that low flush toilets or toilets utilising vacuum systems will be used when there is a requirement for flush water, as this is important for both sustainability and for minimising storage requirements.

The systems discussed in Table 21 are highly innovative and many have not yet been developed to full-scale. There are therefore no comparable costs for the systems.

Table 20: Comparison of innovative toilets

	Urine separation toilet	Urine separation post-toilet	Waterless urinal cartridge
Applicability			
Boat (<6 passengers)	Potential	Potential	Potential
Boat (6-20 passengers)	Potential	Potential	Potential
Coach	Potential	Potential	Potential
Motor home	Potential	Potential	Potential
Train	Potential	Potential	Current
Inputs (including treatment as specified in notes)			
Water	Low	Low	Nil
Energy	Low	Low	Low
Chemical	Nil	Nil	Nil
Final products			
Water – reuse	No	No	No
Solid–fertiliser	Yes	Yes	Yes
Urine-fertiliser	Yes	Yes	Yes
Social acceptability	Low - medium	High	High
Commercial systems			
Example ($\leq$ 6 pax)	Gustavsberg Dubbletten	Aquatron	Falcon Waterfree Technologies
Cost [Note 1] ($Aus 2003)	?	875	?
Note	2	3	4

NOTES

1. *All costs have been converted to 2003 Australian dollars. They do not include treatment facilities.*
2. *Low flush. Urine to storage or perhaps evaporation. Faeces to dry composting. Discharge from system only with pressure on seat, thereby eliminating odours.*
3. *As for the urine separation toilet.*
4. *No water required. Couple with urine storage or evaporation system. Dry composting toilets could be run in parallel to eliminate the need for flush water.*

Table 21: Comparison of innovative single toilet treatment systems

	Ionisation for odour removal	Membrane technology	Electro-flocculation	Distillation
Applicability				
Boat (<6 passengers)	Potential	Not economic	Potential	Not economic
Boat (6-20 passengers)	Potential	Potential	Potential	Not economic
Coach	Potential	Potential	Potential	Not economic
Motor home	Potential	Not economic	Potential	Not economic
Train	Potential	Potential	Potential	Potential
Inputs				
Water	N/A	Low	Low	Low
Energy	Medium	High	High	High
Chemical	Nil	Low	Electrodes	Nil
Final products				
Water – reuse	N/A	Yes	Yes	Yes
Solid–fertiliser	N/A	No	No	No
Urine-fertiliser	N/A	No	No	No
Social acceptability	High	High	High	High
Commercial Example	Bentax	Various	Not developed	Not developed
Note	1	2	3	4

NOTES

1. *Couple with any single toilet system for odour removal..*
2. *High degree of wastewater treatment available. Can be used for liquid treatment alone if coupled with urine separation technology.*
3. *Process would require significant further development before being used commercially.*
4. *High quality effluent produced for reuse. May be best coupled with urine separation system.*

Chapter 5

Single System Design

Introduction

This chapter presents a procedure for the design of single toilet systems based on the requirements of users and available technology. It stresses the use of environmentally sustainable options.

Ideal System

With respect to sustainability on environmental, social and economic factors, it appears that the following may represent a best option:

- no flush water[14] thus eliminating the need to store fresh water and treat wastewater;
- the use of separating toilet thus reducing the pathogenic contamination of urine and simplifying its treatment;
- urine collected through waterless urinal cartridge thus eliminating odours and the need for flush water; and
- faeces and toilet paper to drop to composting or evaporation system via a covered/ hidden system that does not allow users to view contents of composting system.

In some cases a minimal flush will be required and then the ideal system would directly utilise the lightly contaminated water collected from the accompanying hand basin as flush water.

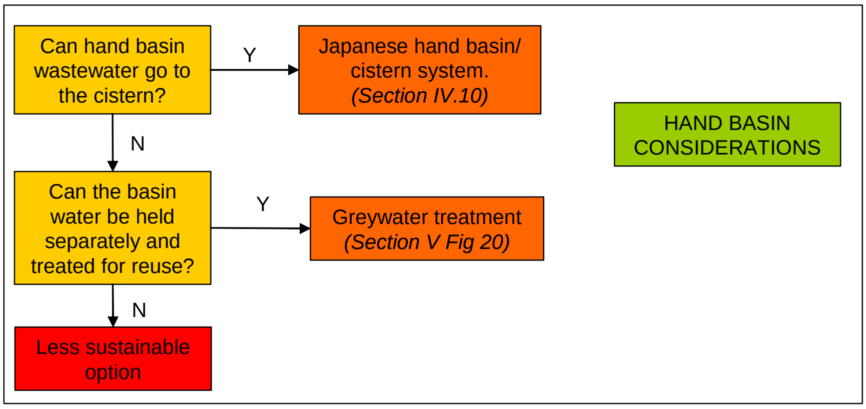
Initial Considerations

The initial design of a single toilet system will be based on a number of criteria; Figure 19 and Figure 20 summarise these with respect to hand basin and toilet types.

The questions posed in Figure 19 and Figure 20 should be considered from the user's viewpoint as they are meant to establish user preferences and not technical feasibility.

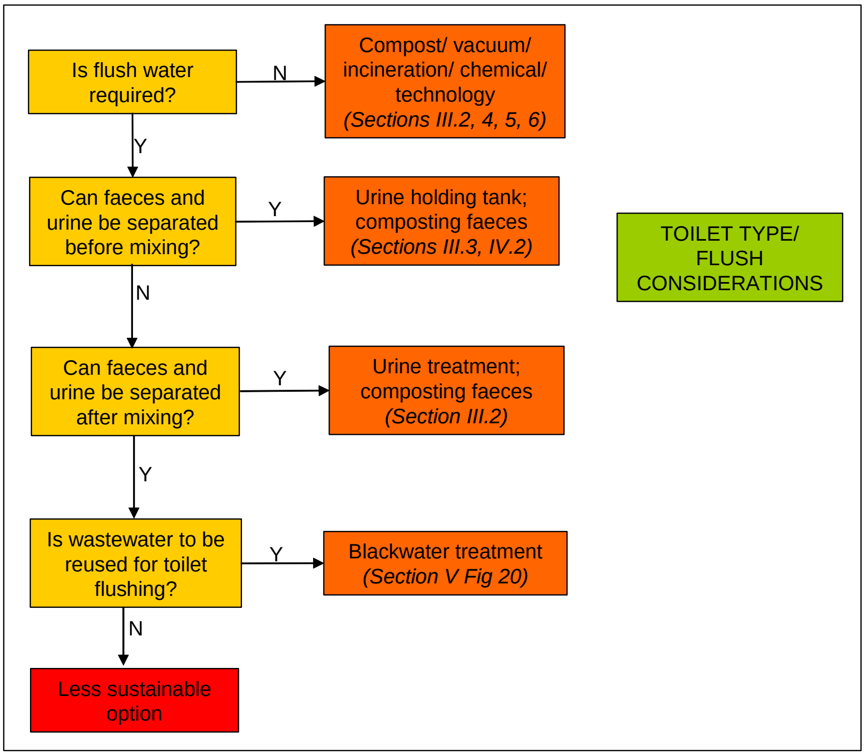
These figures are intended to provide a decision matrix that can be used without the reader having read the rest of the report. Relevant sections of the report are italicised in the diagram so that the reader can easily access pertinent information.

Figure 19: Initial design considerations (hand basins)



[14] It is assumed that commercially available moist towelettes would be used to clean users' hands.

Figure 20: Initial design considerations (toilet type)



In addition, if a flushing toilet is to be used, the volume of flush water must be decided.

This procedure in combination with Table 1 to Table 5 and consideration of the relevant legislation should set the design parameters for the single toilet system.

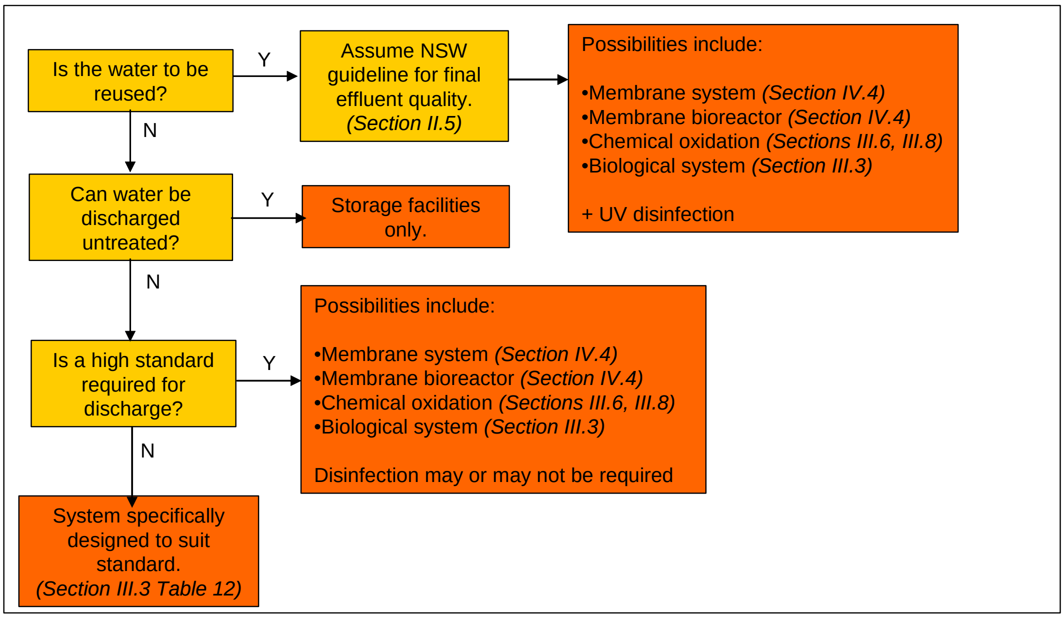
Blackwater Treatment System Design

This section assumes that flush water is to be used, and that treatment is required for discharge or reuse. The selection of a blackwater treatment system will be based on a number of criteria the most important of which are:

- vehicle type (boat, train, coach or motor home),
- number of users (<6, 6-20 or <50),
- method, if any, of separating urine and faeces (separating toilet or after toilet),
- user expectations (high perceived quality or high environmental sustainability), and
- requirements/ option for discharge or recycle.

Figure 21 indicates the various technologies that can be utilised to treat blackwater given the constraints on final effluent quality. These systems can also be applied to grey water.

Figure 21: Blackwater treatment considerations



Chapter 6

Conclusions & Recommendations

Introduction

The final chapter of this report summarises the research outcomes and indicates directions forward.

Reply to Initial Aims

Water minimisation and recycling acknowledges the triple bottom line of the community, the environment and the economy. The single toilet systems presented within this document have been compared on the basis of their sustainability and applicability to the various forms of transport: boat, coach, train and motor home.

It has been found that the most environmentally and potentially economically sustainable system is that which requires no fresh water, minimises treatment requirements and allows for the waste products to be recycled. This is achieved by the use of urine separating toilets coupled with urine storage and faeces composting or dehydration. The question with respect to the system is how socially sustainable it will be and this is something that may only be addressed through trial and public education. It is encouraging that Scandinavian systems have, on the whole, been well received.

Another disadvantage is that, although there are commercial outlets for separating toilets and composting systems that would allow such a system to be readily sourced and implemented, they are not all Australian based. This will increase the cost of such a system and until the various units are manufactured in Australia, other more readily-available, but less sustainable systems, may be employed instead.

Such a combination of urine separation and faeces composting would also be applicable for those systems where a small volume of water was employed for bowl cleansing. This would require fresh water storage but this could be reduced if a Japanese hand basin toilet was utilised.

As there are many different requirements that need to be taken into account in the selection of a toilet system for a passenger vehicle, it is impossible to present an exact guide to the optimum system for installation. Decision trees were therefore constructed to allow applicable systems to be highlighted for potential operators.

It also should be noted that although commercial examples have been given for each technology, the list is not exhaustive and it is possible that many more distributors exist. Suppliers nominated in this report could be used as a 'first port of call' and then alternative companies investigated.

Recommendations for Further Research

Further research into single toilet systems for passenger vehicles will need to be driven by industry. This report indicates that there are a number of innovative solutions, such as distillation and membrane technology, which require development before they can be applied. Additionally, new technologies, that are successfully utilised overseas, such as urine separation toilets, have been identified and these may also merit further research if a potential market is apparent.

It would be interesting to assemble, operate and trial the system identified as the ideal:

- no flush, separating toilet,
- waterless urinal cartridge,
- faeces composting or dehydration, and
- urine storage and application to land.

However it is recommended that this only be undertaken with the interest of an appropriate industry group.

Appendix A: List of Suppliers

Product	Company	Address	Phone	Email
Aqua-san	AMI	U3/13 Commercial Drive ASHMORE QLD 4214	(07) 5503-0217	amiqld@ozemail.com.au
Aquatron	Aquatron International	Box 2086 SE-194 02 Upplands Väsby, Sweden	(0011) 46-8-590 304 50	info@aquatron.se
Auto-San	Auto-San	984 Mt Cotton Rd MT COTTON QLD 4165	(07) 3206-6805	autosan@optusnet.com.au
Chemicals	Additive Inc.	5915 N. Broadway Denver Co 80216 USA	(0011) 1-303-292-0595	info@additives inc.com
Chemicals (including Fiamma)	Camec	Bldg 3, Archerfield Industrial Park ARCHERFIELD QLD 4108	(07) 3710-9000	http://www.camec.com.au/ contact.htm
Dubbletten separating toilet	BB Innovation	Carl Larsson V30 168 50 Bromma Sweden	(0011) 46-8-380-42103	info@dubbletten.nu
Ecolet composting toilet	EcoTech	488 West Coast Rd Awanui 0500 NZ	(0011) 64-9- 406-7546	ecotech_nz@xtra.co.nz
Electrofloc-culation	Electropure Australia	242 Canterbury Rd CANTERBURY NSW 2193	(02) 9787 6333	info@electropure.com.au
Envirolet composting toilet	Envirolet. new zealand	99 Bronte Rd RD1 UMO Nelson 7152 NZ	(0011) 46-508-486-453	peterbusch@clear.net.nz
Enviro Loo	Enviro Options Australia	12 Immarna St ALBION QLD 4010	(07) 3256-2800	allan@envirooptions.com.au
Equaris reactor	Equaris	15711 Upper 34th St Afton MN 55001-0006 USA	(0011) 1-651-337-0261	mail@equaris.com
Gasaloo	All Gas Equipment	8 Waikiki Court, WEST LAKES SA 5021	(08) 8341-5281	
Gustavsberg separation toilet	Berger Biotechnik	Juliusstraße 27 D-22769 Hamburg Germany	(0011) 49-40-439-7875	info@berger-biotechnik.de
Incineration toilet (van based)	Rama Robots	201 Rama Head Office Bldg 2-1-17 Shin Koyasu Kanagawa-Ku Yokohama 221-0013 Japan	(0011) 81-45-402-6117	jaqath@ramadbk.co.jp
Lectra/ San	Raritan	530 Orange St Millville, NJ 08332 USA	(0011) 1-856-825-4900	techsupport@raritan.com
Marine toilets	Jabsco US	20 Icon Foothill Ranch, CA 92610 USA	(0011) 1-949 - 609-5106	http://www.jabsco.com/ contact_us2.html
Microflush toilets (trains)	Microphor	452 East Hill Rd Willits CA 95490 USA	(0011) 1-707-459-5563	info@microphor.com
Omnipure	TSF Engineering	1-5 Prosperity Pde WARRIEWOOD NSW 2102	(02) 9997-2200	tsfsyd@bigpond.com
Ovation distillation	Ovation Products	395 East Dunstable Rd Nashua NH 03062 USA	(0011) 1-603-891-3224	info@ovationproducts.com
Pepcon – NaOCl generation	Pepcon Systems	10622 N. 6400 W. Cedar City, UT 84720 USA	(0011) 1-435-965-5000	gsmith@apfc.com
Portable toilets (Fiamma)	Camec	Bldg 3, Archerfield Industrial Park ARCHERFIELD QLD 4108	(07) 3710 9000	http://www.camec.com.au/ contact.htm
Sawi biocom toilet	Berger Biotechnik	Juliusstraße 27 D-22769 Hamburg Germany	(0011) 49-40-439 78 75	info@berger-biotechnik.de

Product	Company	Address	Phone	Email
Separett Villa Ecological Toilets	Ecovita	PO Box 1313 Concord, MA 01742 USA	(0011) 1-978-318-7033	info@ecovita.net
SOG Ventilation	Aussie Traveller	989 Kingsford Smith Drive EAGLE FAMR QLD 4009	(07) 3868-3868	enquires@aussietraveller.com.au
Thetford porta potti	Thetford	Waterview Close HAMPTON PARK VIC	(03) 9702-9222	info@haymanreese.com.au
Vacuum toilets (train/ boat)	Evac	1702 Hutchins Rd Machesney Park, IL 61115 USA	(0011) 1-815-639-7700	http://www.envirovacinc.com/contact.asp
Vacuum toilets (train)	Semco Vakuumteknik	PO Box 157 226 Svendborgvej DK-5260 Odense SØ Denmark	(0011) 45-65-68-33-00	sfh@semco-vt.dk
Waterfree urinal cartridge	Waterless South Pacific	PO Box 120 Waiwera, Hibiscus Coast 1240 NZ	(0011) 46-649-4266-796	sales@waterless.co.nz

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Glossary

ANZECC: Australian and New Zealand Environment and Conservation Council

ARMCANZ: Agriculture and Resource Management Council of Australia and New Zealand

Black water: water from flush toilets (faeces and urine with flush water)

BOD: biochemical oxygen demand

Brown water: blackwater without urine or yellow water

cfu: colony forming unit

COD: chemical oxygen demand

E. coli: Escherichia coli

EP: equivalent population, the number of persons who would contribute the same quantity and/or quality of domestic sewage as the establishment or industry being considered

Grey water: washing water from kitchen, bathrooms, laundry etc. without faeces and urine (sometimes kitchen water, also called green water, is separated from greywater due to the high concentration of fats, oils and greases)

HRT: hydraulic retention time

IMO: International Maritime Organisation

N: nitrogen

NHMRC: National Health and Medical Research Council

MSD: maritime sanitation device

MSQ: Maritime Safety Queensland

NH_4-N: ammoniacal nitrogen

NTU: Nephlometric turbidity unit

NO_x-N: nitrate and nitrite nitrogen

P: phosphorus

QR: Queensland Rail

RO: reverse osmosis

SS: suspended solids

TKN: Total Kjeldahl nitrogen

TOC: total organic carbon

TSS: total suspended solids

Yellow water: urine from separation toilets and urinals (with or without water for flushing)

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