

INNOVATIONS FROM SCANDINAVIA: INCREASING THE POTENTIAL FOR REUSE

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Abstract

Scandinavia is at the forefront of reusing the by-products of sewage. In Scandinavia, sewage is seen as a valuable resource, not simply as a waste product to be treated and disposed of with the least possible risk to public health and the environment. Where possible, the by-products of sewage are recycled to agricultural land, closing the loop from food to excrement to fertiliser to crops and back to food. A key to the successful reuse of sewage is source separation. Two innovations, the Aquatron™ and urine-separating toilets, separate faeces and urine out of blackwater before it flows into the septic tank. The Aquatron is a wet composting system receiving only blackwater. Solids and water separate in the Aquatron. Solids fall into a container below and are digested by worms before being recycled back to the land. The water spins off to join the household greywater for treatment.

Urine-separating toilets have a small 'dam wall' in the front of the bowl to collect urine. From there, urine flows to a storage container. After six months of storage the urine is sprayed on or injected into agricultural land. A further advantage of source separation is that the resulting greywater can be designed to contain either high or low levels of nutrients in accordance with the end use, or nutrients can be recovered from the greywater before it goes to a land application.

Another Scandinavian innovation, Leca™, an ultra-light, porous, baked clay pellet, is an effective addition to the treatment train, successfully reducing phosphorus and nitrates in sewage effluent. Source separation enables subsequent sewage treatment systems to operate more effectively and have a longer efficient life, as well as reducing the public health and environmental risks from pathogens and nutrients.

Keywords:

greywater, phosphorus, Scandinavia, source separation, urine-separating toilets, wet composting

1 Introduction to Resource Recovery

The Scandinavian philosophy behind innovative sewage treatment is that sewage is a resource with nutrients that should be returned to farmland and not discarded to waterways (Etnier, *et al.*, 1997, Hellström & Johansson, 1999, Johansson & Lennartsson, 1999, Sundblad & Johansson, undated). Therefore, it is important that trade waste has a separate waste stream to sewage. The end product of sewage must be high in nutrients, low in toxic compounds and have a limited public health risk. Sewage from a single person contains enough nutrients to produce 200 kg of grain (Table 1) (Sundblad & Johansson, undated). The per capita annual discharge of domestic sewage in Norway contains 4.5 kg of nitrogen, 0.7 kg of phosphorus and 35 kg of organic matter. Nutrients in sewage from the total population (4.5 million people) are equivalent to 15% of the artificial fertiliser used in Norwegian agriculture. In 1997 this was valued at US\$30 million (Etnier, *et al.*, 1997).

Table 1: Nutritional Requirements of 200 kg of Grain compared with the Excrement from One Person (Sundblad & Johansson, undated).

Nutrients	Urine kg/p/yr	Faeces kg/p/yr	Nutrient demand for 200 kg grain
Nitrogen	5.1	0.6	4.5 kg
Phosphorus	0.4	0.2	0.6 kg
Potassium	0.9	0.15	1.0 kg

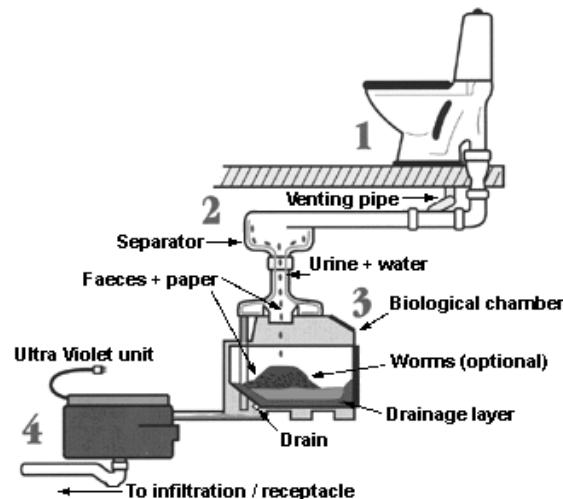
Of the four Scandinavian countries, only Norway has the potential to capitalise on the reuse of sewage nutrients for food crops, as the other countries are banned from using urine or biosolids (composted sewage sludge) on food crops under a European Union (EU) directive. However, Norway, although not part of the EU, is also restricted, as its crops for export must meet EU standards. For the present, Scandinavia is largely limited to recycling sewage to fodder crops for livestock production.

This paper presents three Scandinavian innovations designed to recover nutrients from sewage to close the agricultural loop, which simultaneously reduce the load of nutrients, organic matter and pathogens discharged to waterways and reduce environmental pollution.

2 Source Separation with the Aquatron™

The Aquatron™ is a Swedish wet composting system designed to separate solids (faeces and toilet paper) from the liquid portion of blackwater (urine and water) following the conventional 'water closet' toilet (Del Porto & Steinfeld, 2000; Harper & Halestrap, 1999; Grant, *et al.*, 2000). Greywater from the house, school or apartment block is piped separately to a greywater collection tank. The Aquatron is a single plastic unit moulded in the shape of an hourglass, with no moving parts and needing no electricity. Below the Aquatron unit is a chamber for the collection of solids. The Aquatron unit and collection chamber can be installed below the floor of the toilet or adjacent to the toilet behind the house. After the toilet is flushed, blackwater flows along a pipe that must enter the top of the Aquatron at 4° from the horizontal for the apparatus to function correctly, as shown in Figure 1. Where the influent pipe is horizontal with the orifice of the Aquatron unit, excess water enters the collection chamber, inhibiting solids degradation and causing foul odours.

After entering the Aquatron the water component of the blackwater spins around the inside of the hourglass shaped unit by centripetal force while the solids fall through the middle to the chamber below. The collection chamber houses a vermiculture system that reduces the volume of solids by 90% over time. Toilet paper entering the collection chamber does trap some toilet water. This water drains from an outlet in the bottom of the collection chamber to join the rest of the toilet water that has drained from the base of the Aquatron. This combined liquid passes through an ultra-violet disinfection unit before it is piped to the greywater collection tank (Figure 1).

Figure 1: Aquatron™ (separator) with collecting chamber and ultra-violet unit.

Decomposed solids are removed from the collection chamber 3 to 5 years after the system has been commissioned. In New South Wales the decomposed solids must be buried in a hole in the ground for three months before being used as a garden fertiliser for non-food plants. This feature of separating solids from water and eliminating the conventional septic tank is ideal for areas where it is not possible to pumpout or desludge septic tanks i.e. island and coastal communities with no road access. The added bonus is the opportunity to close the loop from food to excrement to soil to plants and avoid the discharge of nutrients to a water body, as happens when the solids from a septic tank are treated at a municipal sewage treatment plant. The disadvantage of the Aquatron, when compared with other wet composting systems, is that because it only takes blackwater, the Aquatron cannot treat any of the solids or grease in greywater. However, kitchen scraps and paper can be added to the vermiculture system via a hatch at the top of the collection chamber. The optimal temperature for composting is 12° to 25°C. For ease of recovering the composted solids, two collection chambers can be installed. Mark Moodie of Elemental Solutions Ltd (*pers. comm.* 2000) installed a two chambered system at Folly Foot Farm, a working farm and wildlife education centre near Bath, England. It is proposed that after 5 years the second chamber will be commissioned, leaving the first chamber to compost for a further year before worm castings are extracted and dug into the soil around ornamental trees.

In New Zealand approximately 1500 Aquatrons have been installed in homes and schools over the last 10 years. These Aquatrons have been manufactured in New Zealand by Eco-Toilets Ltd. under licence from Sweden. Eco-Toilets manufacture a collection chamber for the Aquatron, especially designed to facilitate easy removal of the composted solids from the base of the chamber. Where the Aquatron is installed adjacent to a building, a small shed is built around the unit to ameliorate fluctuating seasonal temperatures.

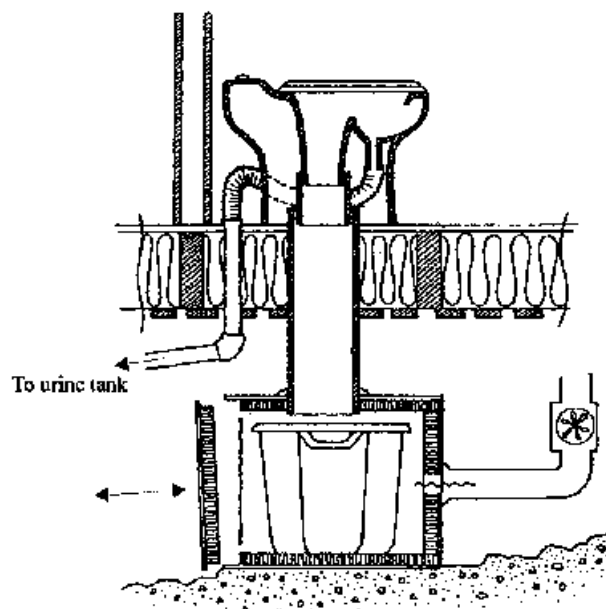
The Aquatron is also an appropriate technology to retrofit failing on-site sewage treatment systems. Whether the septic tank or the land infiltration trench is failing, the Aquatron can take pressure off the system and create a functional system. The septic tank would need to be desludged and cleaned (and made waterproof if necessary) to make it suitable to hold greywater. By installing an Aquatron and solids collection chamber for faecal matter and kitchen scraps, organic matter is largely eliminated from the land disposal system. This enables the soil to absorb effluent from the greywater septic tank more efficiently and over a longer period of time than is possible from a combined black and greywater system.

3 Urine-Separating Toilets

Urine contains more nutrients than faeces. Urine contains 80 – 90% of the nitrogen (N), 90% of the potassium (K) and 50% of the phosphorus (P) in household sewage (Johansson & Lennartsson, 1999). Urine-separating toilets were invented in Scandinavia to reuse the nitrogenous substances and other nutrients in urine in agriculture, to reduce the need for costly fertilisers, to close the food to excrement to crop loop, to decrease the load on wastewater treatment plants and to reduce the polluting effect of nutrients in waterways (Hellström & Johansson, 1999).

Dry composting and flush toilets have been redesigned to incorporate a second bowl in the front section of the toilet bowl (Fig. 2). A small wall separates the urine collection area from the faecal deposition area i.e. the front bowl from the back bowl. A fine water spray (0.2 L) or air suction is used to flush or draw urine from the front bowl through a pipe to a urine collecting tank. The collecting tank varies in size depending on whether it is servicing a house, school, or large building with multiple toilets. When the tank is full, the urine will remain in the tank for a further six months. The European Union has made a directive that urine must be stored for six months before reuse, to allow sufficient time for pathogen die off. When installing urine-separating toilets, organisations contract with a local farmer for urine reuse. After six months storage the farmer drives a tanker to the building and siphons the urine from the collecting tank to the truck. Using a tractor the urine is sprayed onto or injected into farmland used for fodder crops or growing grass. The trend is now to inject the urine, as aerial spraying causes foul odours. The European Union has also given a directive that urine can no longer be used on food crops, so the reuse potential is limited in Sweden, Denmark and Finland.

Figure 2: Urine-Separating Toilet as part of a Dry Composting (WM Ekologen) System (Etnier et al., 1997).



Retrofitting public buildings is relatively simple, as men's toilets already have urinals. Only women's toilets need to be retrofitted with urine-separating toilets. This does not require any change in cultural toilet habits. However, when a urine-separating toilet is installed in a house a cultural change is needed - men need to sit down to urinate. An added benefit of urine-separating toilets, especially for composting toilets, is that faeces have no unpleasant odour.

4 'Designer' Greywater

A further advantage of source separation is that the resulting greywater can be designed to contain either high or low levels of nutrients in accordance with the end use, or nutrients can be recovered from the greywater before the effluent goes to a land application. If the surrounding land or waterways are environmentally sensitive low nutrient levels will be required. Otherwise, if the effluent can be used to water and fertilise garden plants and lawn, a higher nutrient level will be a valuable asset, saving the expense of potable water and fertiliser.

Greywater is generally devoid of urine, except when the greywater contains effluent from the Aquatron. A urine-separating toilet can be installed with the Aquatron to avoid urine entering the greywater system. Greywater can be designed to have high or low levels of nutrients, by including or excluding urine and by using household cleaning products with varying loads of phosphorus. Urine combined with greywater containing 'normal' levels of phosphorus from phosphorus containing detergents, creates a nutritious resource with a P:K:N ratio suitable for plant growth. Where low nutrients are required in environmental sensitive areas (to avoid weed invasion on land and eutrophication of waterways), low phosphorus household and personal cleaning products (and urine-separating toilets with Aquatrons) will reduce the potential for nutrients entering the greywater stream. A further step is to eliminate nutrients from greywater by adding other elements into the treatment train. Several products, bauxite tailings or 'amended soil', ultra lightweight aggregate (LWA or Leca™), Zeolite and crushed red brick, have all been found to adsorb phosphate and nitrogenous compounds to varying degrees. Greywater (or combined black and greywater) passes through a bed of the selected material before the effluent enters a land disposal system.

5 Phosphorus Removal

In Norway, sewage effluent discharged to streams must contain less than 1 mg/L of phosphorus, because many waterways are highly polluted with nutrients from agriculture (Jenssen, 2000). A Norwegian innovation, Leca™ an ultra-light weight, porous, baked clay pellet, is an effective addition to the treatment train, successfully reducing phosphorus and nitrates in sewage effluent. The pellets are sourced from clay high in iron (Fe), aluminium (Al), magnesium (Mg) and / or calcium (Ca) and fired at 1200°C for four hours in a 65 m long kiln. Organic matter and water within the clay vaporises at this high temperature leaving numerous pores in an expanded ceramic pebble. The lightweight aggregate can be crushed to different sizes for various purposes. Aerobic pre-treatment and low loading rates are required for optimal phosphorus and nitrogen removal. A biofilm on the LWA consumes nitrates, while phosphorus is adsorbed onto Fe, Al, Ca and Mg sites on the surface and in the pores of the pellets.

A typical treatment train is: 1. septic tank, 2. aerobic sand filter for nitrification, 3. anaerobic sand filter with reeds for denitrification, and 4. a bed of Leca™ (pH 10 –11) for phosphorus and nitrate removal. The level of P in the effluent from such a treatment train is 0.25 mg/L (Jenssen, 2000). LWA can also be used as the primary treatment medium. At a school near Oslo, a large bed of Leca is finely sprayed with raw effluent from the septic tank. The effluent is sprayed under high pressure so that the nozzles do not clog. A typical effluent output for a similar system can be seen in Table 2 (Johansson & Lennartsson, 1999).

Table 2: Effluent Quality after LWA treatment

Parameter	Reduction
Phosphorus	>90%
BOD	>75%
Nitrates	Up to 40%
Ammonium-N	Up to 80%

Other materials are capable of adsorbing P, but not as effectively as LWA (Table 3).

Table 3: Phosphorus (mg) Uptake per kilogram of Sand, Clay and Leca.

Substrate	P adsorption rate mg/kg
Weathered Sand	600
Clay	250 to 1500
Leca™	Up to 12,000

An adsorption rate of 4,000 mg/kg is typical for Leca™ over a 15-year period. The volume of Leca™ required per person is 0.3 m³ per year. For a four-person household, this equates to 18 m³ for 15 years. LWA takes up less space than a Norwegian sand filter because of the higher ratio of void space to substrate. It is asserted that Leca™ will continue to adsorb phosphorus for 20 to 25 years, after which time the LWA is dug up and reused as soil conditioner, slowly releasing its nutrients to plant roots (Jenssen, 2000). Showing that, unlike many other P adsorbing or flocculating products, Leca™ can be completely recycled leaving no waste product. In addition it closes two loops – that of LWA from clay back to soil, and nutrients from food back to nutrients for plants. This is ecological sustainability at its best.

6 Conclusion

Scandinavia is at the forefront of recycling sewage nutrients in the western world. The emphasis is on resource recovery not just safe disposal. A product is a resource where it is needed and can be a pollutant where it is not needed. Recovering and recycling the products in sewage (nutrients, organic matter and water) enables a potential pollutant to become a resource and eliminates the potential for environmental degradation. Closing the agricultural loop with sewage by-products reduces the cost of fertiliser and food, and avoids the otherwise added costs of environmental impact and restoration. Harvestable and renewable crops, especially fodder, fibre, flowers and tree crops are well suited to reusing nutrients and water from treated sewage.

Using the principle of source separation, the Aquatron and urine-separating toilets keep the nutrients and organic matter of excrement out of the household water stream, greatly shortening the sewage treatment train, thereby saving resources through simplified recovery and treatment. Sewage solids and urine are then readily available for simple processing and reuse. Leca™ is a valuable addition to a sewage treatment train, where a reduction in the nutrient content of the effluent is required. The added bonus is that the stored phosphorus and clay pellets can later be recycled to agricultural land or gardens for beneficial reuse. With the addition of these three Scandinavian inventions sewage treatment systems could be reclassified as 'fertiliser reclamation factories' or 'nutrient processing centres' (Etnier *et al*, 1997).

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