# Ecological Wastewater Management; Challenging Assumptions and Developing Contextual Design Solutions

Nick Grant; Consultant and design engineer. Elemental Solutions (Hereford). Withy Cottage, Little Hill, Orcop, Hereford, HR2 8SE.

Chris Morgan; B.Arch, Cert BBE.; Project Architect. Gaia Architects. The Monastery, 2 Hart Street Lane, Edinburgh, EH1 3RG.

## Introduction

Wastewater management is concerned with treating water and waste economically, efficiently and effectively. Ecological wastewater management seeks to further increase efficiencies by integrating water management as carefully as possible with existing natural processes and cycles. Principal objectives include as far as possible tackling problems at source, reducing pollutant dispersal, maximising nutrient recovery and turning waste products into resources.

Popular interest in sustainable development, and its increasing legislative support has been reflected in innovative wastewater management strategies and this is manifest in an increasing number of installations at various scales of operation. Among these new installations, a tendency has been noted to concentrate on the visually impressive or better known technologies to the detriment of less visual, little known or misunderstood technologies which might well have been more suitable to the actual task.

The obvious risk is that installations will not perform as required when gauged by ecological criteria and this will be unfortunate for clients, for the industry at large and for the environment which we are trying to protect.

Insofar as this tendency can be attributed to ignorance of the wide range of solutions, then some knowledge of this range is clearly desirable. A better understanding of the relative merits and drawbacks of various systems is helpful, along with a method to determine the most appropriate technology under a given set of circumstances, to balance an over-enthusiasm for technologies preconceived as 'green'.

This paper will do three things:

> First, it will explain a number of the technologies commonly discussed in some detail with a view perhaps to dispelling certain myths and explaining why some technologies are more appropriate in some conditions than others;
>
> Second, it will give an overview of the available technologies and provide a framework for understanding the major similarities and differences, followed by a method for developing a more contextual, and hopefully more accurate appreciation of issues that need to be addressed, and;
>
> Third, it will discuss a few case studies in which this method has been applied.

The paper is intended to encourage practitioners to adopt a thorough and unbiased approach to specification, to check for compatibility with the project brief and the overall context as well as actual performance and ecological impact before jumping to conclusions. It aims to give the non-water and sewage specialist the confidence to challenge, constructively, the advice and claims of manufacturers and experts, and the basic knowledge to pursue the most suitable course of action.

The scope of the paper is limited to on-site wastewater treatment for sites beyond the reach of mains drainage.

## Challenging Assumptions

**Some selected examples of available technologies**

There are many types of sewage treatment system on the market and almost all depend on physical settlement to remove gross matter followed by a biological treatment stage utilising aerobic microorganisms. Some trickle the wastewater over a suitable media (e.g. a stone or plastic matrix) on which the organisms live surrounded by air. Other systems bubble air into the wastewater and encourage the organisms to form suspended flocks. With either approach the dead organisms, having performed their function are removed or recirculated as sludge leaving a clear effluent with most of the original organic matter transformed into carbon dioxide and soluble minerals.

**Septic Tank systems**

For smaller developments on appropriate sites, this often maligned and misunderstood technology is a natural treatment system that should be given serious consideration as a contender for best practice (1). The septic tank provides physical removal of solids whilst a correctly constructed leachfield or soakaway provides biological treatment, physical filtration and adsorption. A correctly designed and installed system can achieve near potable effluent quality when wastewater passes through just 1m of suitable soil (1, 2).

**Trickling filters**

Settled sewage (e.g. after a septic tank) is distributed over a bed of stone, clinker or plastic media. A fall of at least 1.5 - 2 m is required but pumping the influent or effluent on flat sites uses less energy than an equivalent powered system, see graph 1. Trickling filters are robust and easy to maintain but require more civil works and capital cost than modern package plants.

**Rotating Biological Contactors, RBC, BioDisk®**

RBCs contain a slowly rotating cylinder made up of plastic disks and partially immersed in a tank of wastewater. The microorganisms grow on the surface of the disks and are alternately exposed to air and sewage. This method avoids the need for pumps or compressors. RBCs are available as modules and as package plants for smaller projects. Whilst there are many other types of powered treatment system we have described RBCs as they are used as an example later.

**Reed beds**

This term describes a wide range of technologies (2, 3, 4) from natural wetlands to highly engineered systems. Various reed bed technologies have proved to be highly effective in appropriate situations but there is no reason to consider them a panacea. For example horizontal flow reed beds have been used widely, and with good results, to add a buffer and polishing stage to other biological treatment systems (4). Vertical flow reed beds used in combination with horizontal flow beds are capable of producing high quality effluent with no power input where the site offers a suitable fall (typically 1-2m) and the client is willing to take responsibility for routine care and maintenance.

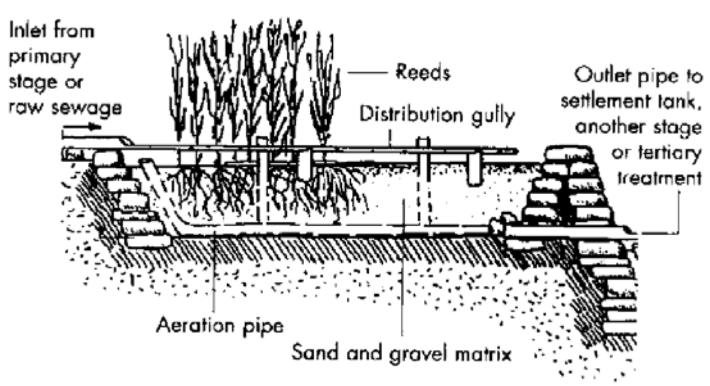



Fig. 1 Vertical flow reed bed schematic (3).

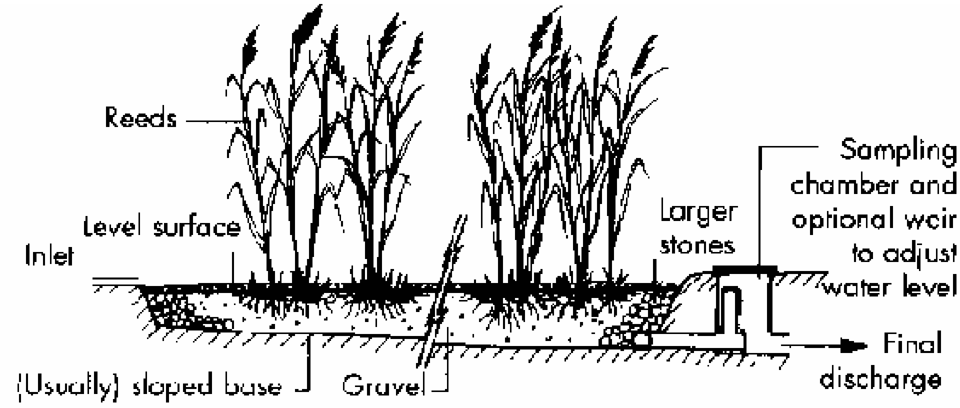
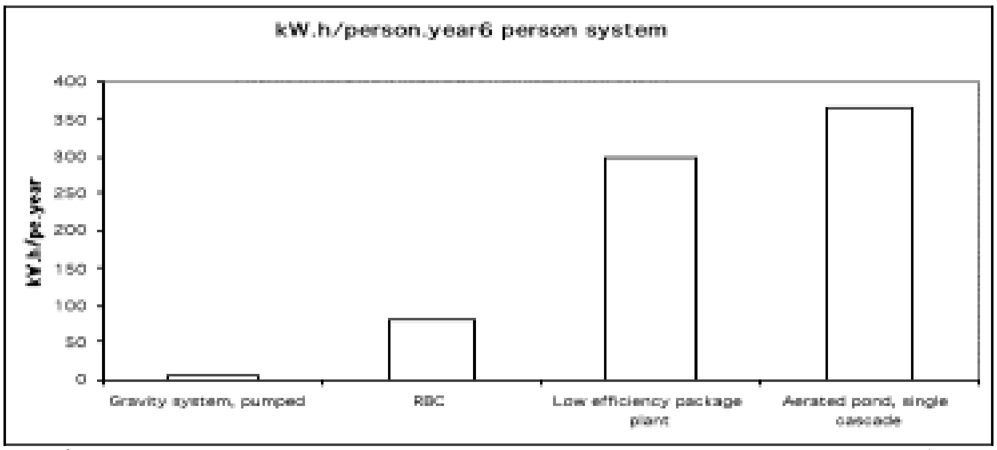



Fig. 2 Horizontal Flow reed bed schematic (3).

**Energy Consumption**




Graph 1. Comparison of energy consumption for 4 sewage treatment systems (it is assumed that no fall is available).

Notes on graph

Figures are for comparison only to illustrate the range of performance. All systems are assumed to provide similar levels of treatment. Energy use per person will vary with system size for all examples except the pumped gravity system.

1. Trickling filter, sand filter, vertical flow reed bed etc with influent or effluent pumped to create the required fall. Energy use proportional to wastewater volume. 6 people x 150 litres/d = 900 l/d. Using a Grundfos KP250 pump, 3m dynamic head:
$8m^3$/h @ 480W = 54W.h/d, say 20kW.h/year

2. Klargester BioDisk, 50W DC motor x 24h/d.

3. Typical consumption of package plant with poor energy efficiency, e.g. continuous air compressor or recirculation pump.

4. Energy efficiency improves for larger systems, some systems use 2 pumps of 250-500W each, 1 x 250W assumed for this example. An assumed green technology.

**Living machines™**

As an example we will consider the technology of Living Machines™. Current UK clients utilising this technology include The Earth Centre, The Body Shop, The Findhorn Eco-Village and The National Botanic Garden Wales.

The Living Machine™ is a wastewater treatment concept invented by Dr John Todd of Living Technologies (8). Typically they utilise a large anaerobic stage, wetlands, aquaculture, and floating macrophytes combined with mechanical aeration in a system housed in a greenhouse. In the UK, living machines may include space heating to protect the plants from frost.

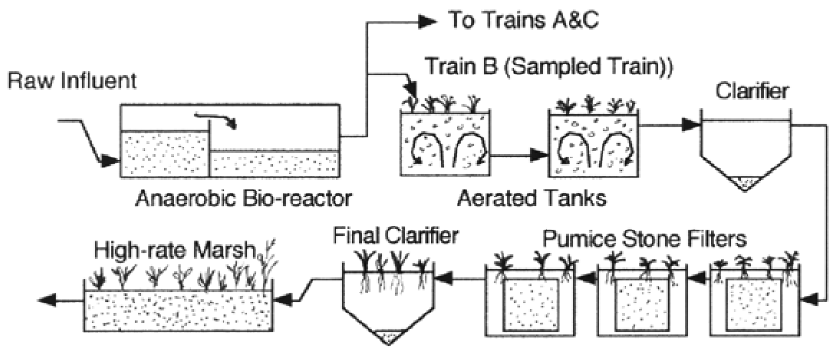


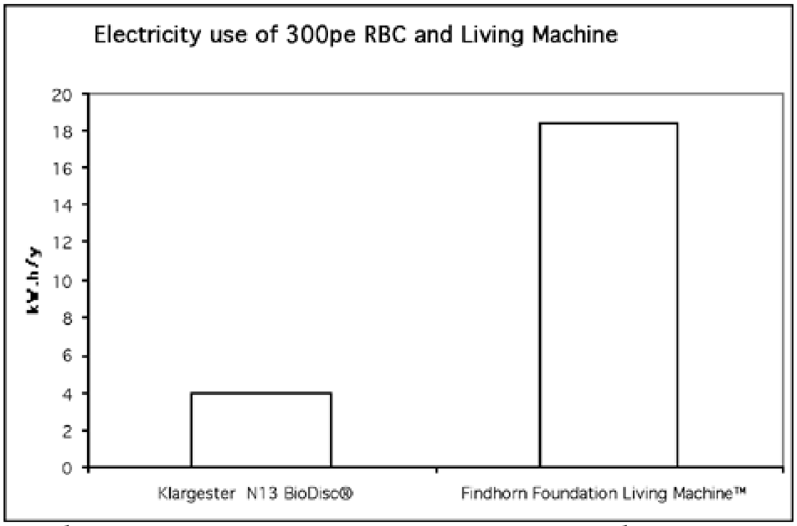

Fig. 3 Schematic of the Frederick, MD "Living Machine" (3)

The Living Machine™ concept is sold as a green technology both explicitly and implicitly. Whilst a watertight definition of 'green' is beyond the scope of this paper, we might expect energy consumption and effluent quality to be better than the implicitly non-green standard technologies (9).

Table 1 and graph 2 compares the 300 population equivalent (pe.) Living Machine™ at Findhorn, Forres with a 300 pe. RBC. A fair comparison of effluent quality is more difficult due to variations in loading and operation between trial sites but what data we do have for Ammonia and $BOD_5$ suggests that, much to the author's surprise, the RBC outperforms the Living Machine.

| Technology: | Klargester N13 BioDisc® RBC | Findhorn Foundation Living Machine™ |
|---|---|---|
| Annual electricity use (approx) | 450W x 24h/d = 3.9MW.h/y | 2kW x 24h/d + 1kW 'intermittent', say 2.1kW = 18.4MW.h/y |
| Other energy use | 0 | Approx. '£800/y gas' to protect plants from frost. |

Table 1. The energy consumption of the Living machine at The Findhorn Foundation in Scotland compared with an equivalent rated RBC by Klargester. The lack of sub-metering has required some, hopefully conservative, assumptions to estimate energy use.




Graph 2 Comparison of electricity use of Living Machine and RBC. Heating energy of Living Machine ignored (figures from table 1).

In 1993 and 1994 the US EPA undertook an independent evaluation of the technology (6) which concluded that:

The Living Machine on trial could meet effluent quality goals for $BOD_5$, COD, TSS and provided effluent with faecal coliform concentrations<200/100ml.
The Living Machine on trial did not meet effluent quality goals for P, $NH_3$ or TON.
The plants provide marginal contribution to treatment efficiency but do enhance public acceptance of a treatment facility.
The residual sludge and plant material is equivalent to that from an equivalent sized conventional plant.
Life cycle costs were comparable for smaller installations but higher than conventional technologies at flow rates above $200m^3$/day.
Solar energy played an incidental role in the 'Living Machine™' process.
Claims that the 'Living Machine™' is a unique and distinct technology are not warranted.
The 'Living Machine ™' may find application at flow rates <$200m^3$/d for small subdivisions, schools, condominiums and commercial developments where the enhanced aesthetics will encourage public acceptance of the process compared with conventional systems.

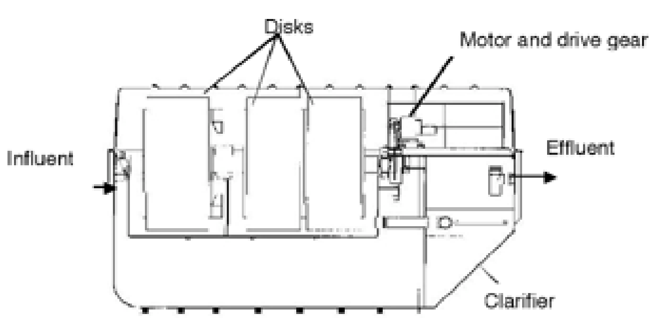



Fig. 5 Klargester N13 RBC for up to 300 population equivalent.

## Developing Contextual Design Solutions

**Available technologies**

The following grouping provides an alternative to the green/conventional split that we consider misleading:

**Available technologies**

**Radical solutions**

Technologies that avoid the problem rather than end-of-pipe solutions. Sometimes difficult to retrofit. Usually easiest to apply at the design stage.

- Dry toilets - avoid the generation of wastewater and the need for a water supply.
- Grey water irrigation or reuse - reduces or eliminates the generation of wastewater to be treated, saves drinking water.
- Stormwater source control and rainwater reuse - reduces the load on combined sewers, eliminates point source pollution (e.g. hydrocarbons), can eliminate the need for storm sewers or flow balancing tanks.

**Extensive systems**

Large and robust, zero or low energy consumption. Appropriate choice of system will depend on soil type, available falls and area etc. Loading rates limited by oxygen transfer between atmosphere and wastewater and or retention time.

- Passive ponds and lagoons-large, ideal in heavy clay, may incorporate aquaculture.
- Leachfields-hidden, good solution in suitable soil (arguably 'passive intensive')
- Land treatment-low cost, possible 'planning' issues.
- Wetlands, horizontal flow reed beds-performance and clogging issues to address.
- Sea or river- may be illegal but the poison is the dose. In all systems the wider environment continues the treatment process.

**'Passive intensive'**

Often evolved from extensive systems offering a smaller footprint at the cost of engineering complications. These systems use a vertical flow regime making use of gravity to improve the availability of oxygen.

- Trickling filters (biofilters) - would be green if plants could be added
- Sand filters-little used in the UK but can produce very good effluent, various types
- Vertical flow reed beds - sand filters with plants

**Extensive with energy input**

- Aerated ponds and lagoons - aeration is sometimes added to cope with seasonal variations and occasional odours. Some 'green' domestic systems use an order of magnitude more electricity than some package plants
- Living machines™, this technology will be dealt with in greater detail later.

**Intensive systems**

Typically reduce the system size by using mechanical aeration. Some use chemicals to achieve oxidation, precipitation or nutrient removal and some systems combine biological and chemical processes. Treatment stops when power fails.

- Activated sludge - conventional municipal scale technology
- Package plants - compact pre-built and easily installed systems for small to medium scale applications. Energy use, cost and effluent quality varies considerably between designs.

**Hybrids**

Combinations of any of the above. Typically an intensive first stage followed by an extensive polishing and buffering stage such as a pond or wetland.

- Rotating Biological Contactor (RBC) followed by a horizontal flow reed bed.
- Trickling filter followed by grass plot or soakaway.

**Selecting appropriate technologies**
No technology can be considered appropriate out of context with the application and this section aims to give the reader a straightforward method of approaching the initial consideration of various treatment options.

The first step is to develop a clear brief as to the requirements of the client and the relevant authorities (e.g. EA/SEPA, Planning and Building Control).

Information about the site can then be gathered which will have a bearing on the choice of system.

Check-lists are useful tools to help avoid premature conclusions:

**Design Check-List**
**Some site features to consider**

- Soil type and permeability (good for 'soakaway' or good for ponds?).
- Sensitivity of receiving body, e.g. watercourse, can the wider environment be considered as part of the treatment system?
- Available area.
- Proximity to habitation.
- Public access (safety, vandalism).
- Available fall. Flat sites suit ponds, horizontal flow reed beds and leachfields; sloping sites suit trickling filter, sand filters and vertical flow reed beds.
- Local materials (filter sand, gravel, slag, stone, topsoil, clay).
- Availability of electricity on site.
- Access for machinery and materials.
- Access for sludge removal.
- Visual and aesthetic considerations. Invisible or feature?

**Client/user details**

- Can the problem be eliminated at source? (e.g. cheese factory whey fed to pigs, dry toilets, swales rather than storm drains etc).
- Budget.
- Available maintenance and care.
- Number of people served.
- Per capita water consumption (can this be reduced?).
- Need or potential uses for water or nutrients on site (e.g. dry climate gardens, biomass coppice).
- User acceptability and expectations (e.g. mountain bothy vs hotel).
- Cultural issues.
- Unusual inputs, e.g. photographic chemicals, sterilising fluids.
- Image, PR, system may have to be 'distinctive' to obtain funding.
- Acceptability of risk with experimental technologies.
- Educational value, hidden systems can be interpreted or made exciting with displays.

**Legal**

- EA/SEPA, consents and concerns.
- Planning, Building Regulations, EHO, Water Regulations.
- Wayleaves, land ownership, shared systems.
- Maintenance contracts.
- Performance guarantees.

**Quantitative comparisons**
The sums required to make meaningful comparisons between a range of solutions are usually simple. More subtle considerations may be required at the detail design stage when faced with, for example, choices between different materials or between embodied energy at construction and ongoing energy use.

Usually the differences are large enough to justify a simplistic analysis and a one-off project does not warrant the nut-by-nut environmental impact assessment that would be worthwhile for a mass-produced product.

The following list suggests some simple numbers that can be estimated or obtained from system suppliers in order to compare competing products or evaluate possible solutions:

- Energy requirements.
- Sludge production and removal costs (including energy cost).
- Embodied energy. Can simply compare like with like to simplify analysis. For example compare the weight or volume of plastics and aggregates in each system.
- Effluent quality (typically measured in terms of BOD, suspended solids and ammonia).
- Capital costs.
- Running costs.
- The match between reclaimed water and suitable uses (eg to check claims of water saving for reuse systems).
- Chemical requirements.

**Ranking of priorities**
Another useful process involves highlighting and prioritising key factors. The chosen ranking will reflect personal concerns as well as site and project specifics. With such a list there is no single correct order and, depending on the project, items at the bottom of the list may be either unimportant or simply slightly less important than those above.

If we consider a sewage system for an eco-visitor centre we may argue for the following order:

1. Educational value.
2. Reducing the problem at source (water efficiency, readily degradable cleaners).
3. Energy consumption.
4. Embodied energy, construction/manufacture ecological impact.
5. Potential for widespread uptake.
6. Visual 'statement' or feature, image, inspirational qualities.
7. Cost.
8. Integration in wider system.
9. Effluent quality (assumed adequate).
10. Maintenance requirements.
11. Space.
12. Confidence in established technology.
13. Invisibility.

The authors of this paper will almost always prioritise 'reducing the problem' and in this example we would justify this as a lesson that everyone can take home. In practice 'Visual statement' will usually be put at the top of the list for obvious reasons and this creates a conflict of purpose that could be debated by the design team to facilitate a creative resolution. The important point is that issues are considered, agendas and assumptions are identified and and that the design process is transparent.

## Case Studies

**Case study; Public house and restaurant, Worcestershire**
The existing package plant was failing its consent. An adjacent field was available but the soil was too heavy for a soakaway. The landlord had no interest in green solutions but wanted an economic and easy to understand answer to his problem. The solution chosen was a horizontal flow reed bed following the existing system. The extensive nature of the reed bed evens out the peaks throughout the day and has ensured that the discharge is able to reliably meet its consent.

In this case, the following ranking of relevant factors was adopted:

1. Cost.
2. Confidence in established technology.
3. Maintenance requirements.
4. Invisibility.
5. Visual 'statement' or feature, image, inspirational qualities.
6. Energy consumption.
7. Space.
8. Effluent quality (assumed adequate).
9. Reducing the problem at source (water efficiency, readily degradable cleaners).

Number nine might have been promoted to number one when considering kitchen grease. Numbers four and five need not be mutually exclusive and in this case a very visual system was located discretely.

**Case study; Glencoe Visitor Centre - (design stage)**
The initial proposal for this flagship project was a 'wetland' system with an area of around 1,200$m^2$. This was chosen as a visual statement, an established green technology and for its educational value as part of a proposed nature walk.

Examination of the site revealed that such a system would have been difficult to fit into a landscape with little flat ground. Also a large 'reed bed' would have had an adverse impact on a very sensitive site and would have required the import of around 2,000 T of aggregate and the export of an equivalent quantity of spoil. The survey also revealed the existing trickling filter and settlement tanks to be well hidden in a natural copse but in need of major repair.

Consultation with SEPA (Scottish Environmental Protection Agency) suggested that required discharge standards could be met by upgrading the existing system. However calculations suggested that effluent volumes would be too high for the existing settlement tank. Analysis suggested that waterless urinals, 2/4 litre dual flush WCs, timed spray taps and other measures could more than halve effluent volumes thus obviating the need for a new settlement tank whilst saving energy and reducing the load on the trickling filter. Greywater reuse was considered and rejected due to a poor match between greywater volume and WC requirements and the need for chemical additives with available systems.

When all the considered factors were prioritised an apparently conventional technology proved to be the cheapest and most environmentally benign solution for this particular site.

At the time of writing the authors are deciding between the enlargement of the trickling filter and the introduction of effluent recycling to cope with the increased demand. The former will cost perhaps £10,000 more than the recirculation option and require the use of significant quantities of concrete, steel and plastic media. The recirculation scenario might require 300-800kW.h/year electricity use which is modest for a system handling 245,000 visitors/year. Other factors being considered include the visual impact of the larger passive option, pump reliability, noise and maintenance issues.

In this case, the following ranking of relevant factors was adopted:

1. Reducing the problem at source (water efficiency, removal of surface water infiltration).
2. Space and limitations of site.
3. Invisibility and minimised physical impact of installation.
4. Energy consumption.
5. Maintenance requirements.
6. Cost.
7. Confidence in established technology.

**Case study; Felin Hescwm, residence and holiday accommodation**
The main issue for this site was access as the property is located down a steep, narrow track. This made on-site sludge treatment a priority. Initially the owners took on a trial of the DOWMUS system that replaces the more usual septic tank with a free draining worm bed (7). However, despite various modifications and generous sizing, this Australian technology did not cope with the full hydraulic load of domestic sewage in our cool climate and has evolved to include a self-cleaning separator operating on the Coanda effect. This device diverts most of the water past the compost bed. The liquid effluent is treated and dispersed in a swale area created with live willow and wood-chip, a technique considered particularly appropriate for a site with poor access for heavy materials such as stone and a steep slope unsuitable for conventional soakaways. The aerobic separator effluent is effectively odourless, an important consideration as the system is adjacent to a footpath and a favourite spot where the owners sit and enjoy the sea view.

In this case, the following ranking of relevant factors was adopted:

1. Access.
2. Reducing the problem at source (water efficiency, readily degradable cleaners).
3. Energy consumption.
4. Cost.
5. Maintenance requirements.
6. Visual 'statement' or feature, image, inspirational qualities (interested parties can be shown the system but passers by would be unlikely to notice it).
7. Effluent quality (assumed adequate).
8. Confidence in established technology.
9. Invisibility (see 6).
10. Space.

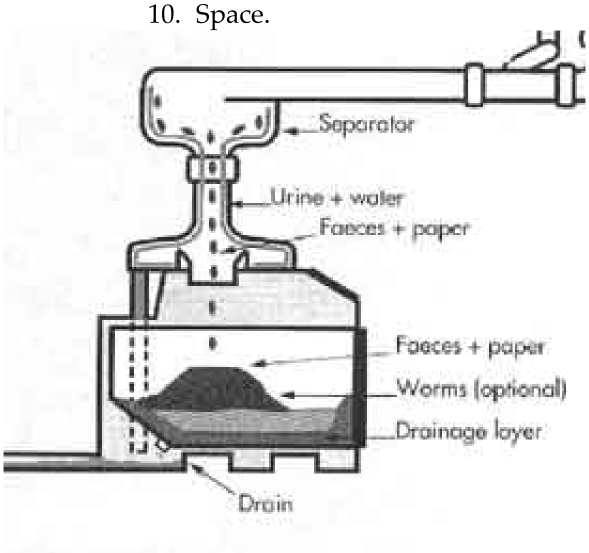



Fig. 6 Schematic of the Aquatron® system, a commercially available variant of the system developed for Felin Hescwm.

## Conclusion
We hope we have been able to encourage the reader to avoid being blinded by the superficial aspects of a technology but to check for compatibility with the site and user as well as for actual performance and ecological impact before jumping to conclusions. We would advocate the application of the same degree of analysis as might be routinely applied to the choice of other building components.

A detailed knowledge of biology or sewage treatment is not required in order to ask the right questions of manufacturers and designers but a broad understanding of the options will help.

Don't be baffled by bulrushes.

## References:

Grant and Moodie, "Septic Tanks; an overview" N. Grant, Withy Cottage, Little Hill, Orcop, Hereford, HR2 8SE. (1995)

Tchobanoglous, G. ed., "Wastewater Engineering; Treatment, Disposal and Reuse" Metcalf and Eddy inc. McGraw Hill. (1991)

Grant, N. Moodie, M. Weedon, C., "Sewage Solutions; Answering the Call of Nature" Centre for Alternative Technology. ISBN 1. 898049 13 0. (1996)

Cooper, Job, Green, and Shutes, "Reed Beds and Constructed Wetlands for Wastewater Treatment" ISBN 1 898920 27 3, WRc Swindon. (1996)

Brix, H., "Function of Macrophytes in Constructed Wetlands" Water Science and Technology; Volume 29 No. 4. pp71-78. IAWQ. (1994)

Reed S C and Salisbury J., "A process evaluation of the AEES 'Living Machine' system in Frederick MD" Contract report 68-C"-01202WA3-18, US EPA  OWEC, Washington DC. (1995)

DOWMUS: http://dowmus.com/home.html

Living Technologies, 431 Pine Street, Burlington, Vermont 05401
http://www.livingmachines.com/index.html

DETR Green Claims Code; http://www.environment.detr.gov.uk/greening/greenpro/gcode.htm