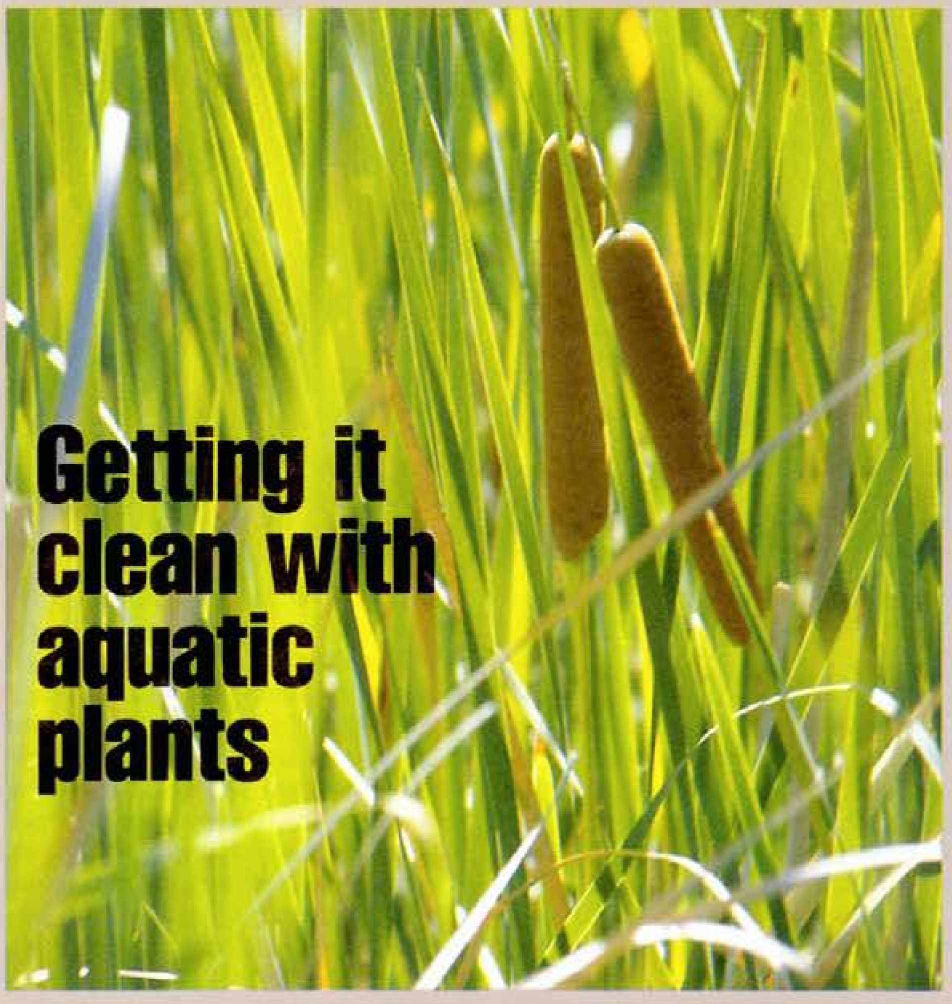


Getting it clean with aquatic plants

Wetlands, swamps, call them what we will, they're probably not the place most of us would look for an ecologically sound way to treat our wastes. Yet in the struggle to live in that halfway house between the terrestrial and the aquatic, many swamp plants have developed some remarkable qualities that make them particularly suitable for cleaning up our dirty water.

Dr David Mitchell and his colleagues at CSIRO's Division of Water Resources at Griffith, N.S.W., are among researchers who have been making use of those qualities, designing and testing systems that use plants instead of chemicals to treat our effluent.

Late last year the scientists lodged a patent application for the design of a low-cost waste-water-treatment system based on aquatic macrophytes (large water plants), a system they believe will benefit households and communities throughout the world. Currently, they are fine-tuning the design and monitoring pilot systems recently installed at Kapooka army barracks, Wagga Wagga, and in households in Wagga Wagga and Griffith. Later this year, with financial support from the Coffs Harbour Shire Council, they plan to install a larger system on the northern coast of New South Wales.

This phase of the research follows a long gestation period and scores of glasshouse experiments and field trials. The early stages of the research program, back in the late 1970s, focused on gaining an understanding of the interaction between plants and effluent, as the team sought an alternative to the more familiar engineering, chemical, and microbiological solutions used to clean waste-water, especially from rural industries.

Aquatic alternatives

The research team led by Dr Mitchell (now seconded to the Murray–Darling Freshwater Research Centre) knew that a key to successfully treating waste-water with aquatic macrophytes lies in their

A decade of effluent later, this Snowy Mountains wetland is still improving the effluent quality: but the species composition has changed markedly.

ability to thrive in a natural habitat where low nutrient levels are likely to limit plant growth and where roots frequently have to grow in conditions where little or no oxygen exists (anaerobic).

Probably because nutrient levels in natural waterways tend to fluctuate widely, many aquatic macrophytes have developed a capacity to absorb large quantities of nutrients quickly and in quantities greater than they need for growth. Irrespective of whether they float like water hyacinths or are emergent plants like bulrushes, it is this ability — which the scientists call 'luxury uptake' — that enables the plants to 'strip' nutrients from waste-waters. And the ability of many swamp plants (especially the emergent macrophytes) to grow vigorously in sediments devoid of oxygen means that they can also tolerate anaerobic effluents.

The idea of using aquatic plants to treat waste-waters is not new. In the past, many of the approaches have concentrated on using floating plants, not just because they 'strip' nutrients effectively, but because they grow very quickly provided they have plenty of space and nutrients, and optimum light and temperature. For example, water hyacinth (*Eichhornia crassipes*) doubles every 6·2 days in sewage oxidation ponds in Florida, U.S.A., while salvinia (*Salvinia molesta*) has been reported to double every 36 hours in nutrient-rich conditions at Mt Isa, Qld.

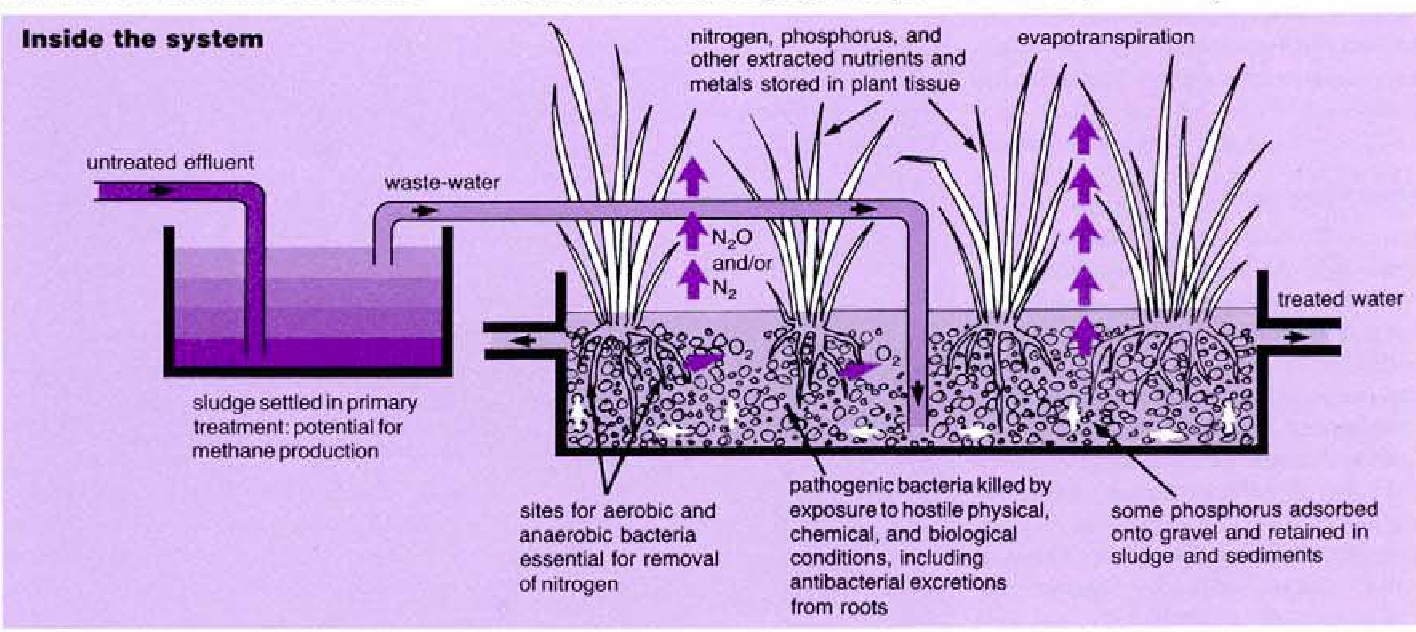
But the rapid growth of these plants can become a double-edged sword; floating plants have caused some disastrous environmental and social problems after finding their way into waterways uninvited (*Ecos* 42 described the spread of salvinia in the Sepik River, Papua New Guinea, and its eventual control). In Australia, many floating plants are now declared noxious weeds. In any case, their use has other drawbacks. Their rapid growth produces large quantities of biomass that must be harvested regularly to maintain their treatment capabilities. In addition, most of the rapid growers are tropical and are only capable of sustained growth when the temperature suits them, so they are not so useful where climate is markedly seasonal.

By contrast, emergent plants need only occasional harvesting, if any, and many grow rapidly in temperate climates. For example, in a single growing season one seed of cumbungi (the Australian common name for species of the genus *Typha*) can produce a network of rhizomes covering several square metres with over a hundred aerial shoots.

But it wasn't just rapid growth that interested Dr Mitchell's team. Some of his colleagues — Dr Max Finlayson (now working at the Office of the Supervising Scientist, Alligator Rivers Region Research Institute, N.T.) and Mr Alan Chick among them — were interested in some other potentially useful attributes of swamp plants and of the swamp ecosystems to which the plants belong.

From previous research, the scientists were aware that swamps act as sinks for particulate matter and for important inorganic nutrients such as nitrogen and phosphorus. They knew that swamp systems can remove these substances from inflowing water, decrease bacterial counts, and lose water by evapotranspiration — all requirements of a waste-water-treatment process. They also reasoned that, as some emergent species actually exude oxygen through their roots to the sediments, the plants would

The artificial 'swamp' cleans up waste-water by removing nutrients, heavy metals, and suspended solids. It also reduces the biochemical oxygen demand and destroys micro-organisms.

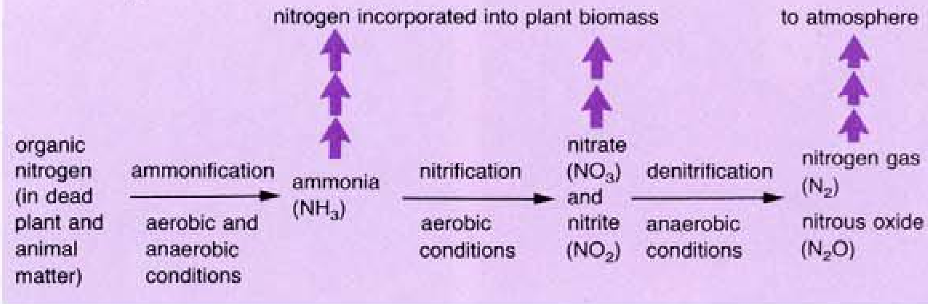


contribute to reducing the high biochemical oxygen demand (BOD) of many waste-waters. Putting oxygen into the water is an essential part of any treatment.

Two final factors encouraged the scientists to look to wetlands for the design of an effective treatment process. One was the apparent longevity of swamp systems (which appear to persist as long as water continues to trickle through them). The other attraction was the idea of developing a system using Australian native swamp plants, which included some already recognised overseas as showing considerable potential for waste-water treatment.

Since the late 1970s, the research team has run trials in glasshouses at Griffith and several collaborative studies, using artificial wetlands to treat effluents from a piggery, a poultry abattoir, a winery, and a domestic sewage-treatment plant. In addition, an opportunity to study the way in which a natural wetland coped with sewage effluent came in 1981.

What happens to the nitrogen



Natural wetlands as an effluent filter

For more than a decade, the village of Thredbo — an alpine resort within the Kosciusko National Park, N.S.W. — had been discharging its sewage effluent into a nearby swamp. Effluent from the village was first treated in an activated-sludge plant, held in four maturation ponds for between 10 and 20 days, then discharged into the swamp. This reduced the outflow of nitrogen and phosphorus to the Crackenback River, which drains into Lake Jindabyne a further 18 km downstream.

A proposal to upgrade the sewage-treatment works to cater for increased visitor accommodation motivated the Thredbo management to seek help from Professor Peter Cullen of the School of Applied Science in the Canberra College of Advanced Education, to find out how well the existing wetland removed nutrients from the effluent, and to gain some understanding of its ecology. In particular they were interested in whether the swamp could be 'managed' to make it more efficient by, say, altering the composition of the plant species. Professor Cullen collaborated with CSIRO's Dr Mitchell, Dr Finlayson, and Mr Chick to carry out the research.

After siting three transects across the wetland — one above the effluent inflow and two below — the CSIRO group identified plant species and measured their dominance, percentage cover, vigour, and insect damage. They took sediment samples from four sites on each transect, and analysed them for nitrogen and phosphorus. In addition, between January 1982 and September 1983, Professor Cullen and his colleagues measured, sampled, and analysed the wetlands' inflow and outflow.

During 1982, the team observed that some of the waste-water flowed through the surface of the wetland in a series of channels, taking about 2 hours from the time the inflow entered the wetland until it reached the Crackenback River. This meant that some of the effluent appeared to be effectively by-passing the swamp; the rest took much longer to pass through. Yet despite this occurrence, during the summer of 1982, the wetland retained 44% of the incoming phosphorus and 65% of the nitrogen. The figures for winter were 10% and 14%.

In the summer of 1983, the scientists sought to increase the time the effluent spent in the swamp, by blocking the surface channels with soil. Unfortunately, the soil washed out in a summer storm. Then they built gravel bunds across the wetland, which reduced the flow and increased the water level. Interestingly, the wetland proved sensitive to physical disturbance; this engineering work was followed by a net release of phosphorus and a markedly reduced retention of nitrogen during the rest of the year.

The vegetation surveys showed that the composition of species changed downstream of the sewage inflow to include more opportunistic weeds, particularly *Epilobium sarmantaceum* — a change, probably influenced by the effluent, that reduced the cleansing efficiency of the swamp. Nevertheless, they considered that the system reduced the load of nitrogen and phosphorus to the river in summer and was a useful addition.

Further work by Professor Cullen and one of his students, Ms Stephanie Brodrick, identified lumps of decaying plant material near the swamp surface as the important site for denitrification — the process by which some nitrogen compounds can be transformed to nitrogen gas by bacterial action. Disrupting these surface sites by earthworks or harvesting will reduce the effectiveness of these natural wetlands in removing nutrients.

Experiments with artificial wetlands

While they were monitoring the natural wetlands at Thredbo, Dr Finlayson and Mr Chick were also studying the performance of three genera of emergent aquatic plants — cumbungi (genus *Typha*), reeds (*Phragmites*), and clubrushes (*Schoenoplectus*) — growing in three separate artificial wetlands they had created to treat the effluent from a poultry abattoir. Effluent was allowed to percolate for about 3 days through plastic-lined trenches, each planted with one of these emergents in gravel. By regularly sampling, the scientists compared the quality of the effluent flowing into and out of the trenches.

Over the period of the study, and after making corrections for evapotranspiration, they found that the trenches significantly reduced the nutrient contents of the effluent: nitrogen by 42–75%, phosphorus by 68–79%, sodium by 7–34%, and potassium by 9–56%. Of the three systems, the clubrush trench performed best.

Importantly, the artificial wetlands also reduced the biochemical oxygen demand of the effluent, which, despite a mechanical aeration system in the storage tank, was anaerobic as it entered the trenches. The reed and clubrush trenches produced aerobic outflows, while the cumbungi trench outflow was usually anaerobic, although much less so than the inflow.

Some of the team's other experiments demonstrated that, efficient as the artificial wetlands could be, the plants just couldn't cope with some highly concentrated effluents. This was the case for effluent that came from a piggery housing 4700 pigs under intensive feedlot conditions, which was tested in glasshouse experiments and as it passed through two experimental trenches, similar to those used in the poultry abattoir. Winery effluent was also too toxic.

In glasshouse experiments the acidic winery effluent, containing a high level of potassium, had the most dramatic effect on

Experimental vertical-flow wetlands — unplanted and planted with clubrushes (above), and each system kept at a constant temperature (below).

plant growth. After 1 week, all plants exposed to the effluent at a concentration of just 30% had died. Piggery effluent had an inhibitory effect: after 4 weeks the cumbungi had died at 60 and 100% concentrations, although roots and rhizomes were alive; at 30% only the outermost leaves had died. However, all the plants in the effluent from the poultry abattoir effluent survived, with the maximum growth occurring at 60% concentration.

In the trench experiments, the scientists diluted the piggery effluent to 25% concentration. BOD fell by 30–40%; while this was not enough to satisfy most environmental standards, the systems removed more than 50% of the nitrogen and phosphorus load. Sodium, potassium, and chloride were also retained by both trenches, despite the outflow concentrations being higher than those of the inflow — an apparent paradox simply explained by the loss of water from the trenches through evapotranspiration. In later studies this loss of water and the associated concentration of pollutants became an important consideration when determining the criteria for evaluating and comparing different treatment systems.

Urban effluent study

In 1983, the Water Resources team led by Dr Mitchell scaled up its trench experiments in a collaborative project with the Water Research Laboratory at the University of Western Sydney, Hawkesbury, and the Water Board, Sydney. The project, co-ordinated by Dr John Bavor from the University, set out to determine the feasibility of using artificial macrophyte systems for the effective removal of sewage constituents from an urban sewage-treatment works. Mr Peter Breen (now with the Dandenong Valley Authority) joined CSIRO at this stage, to conduct the intensive research into the role of the plants in the systems.

The collaborators constructed seven experimental trench systems designed to receive a total of about 400 000 litres of effluent per day or about one-quarter of the total flow from the Richmond Water Pollution Control Plant next to the University at Hawkesbury. They built five macrophyte and two control trenches, each 100 m long, 4 m wide, and 0·5 m deep, lined each trench with an impermeable membrane, and constructed inlet and outlet monitoring and sampling facilities.

Having filled two trenches with gravel, they planted clubrush (*Schoenoplectus validus*) into one and cumbungi (*Typha orientalis*) into the other. They kept the third trench as open water and planted the floating species parrot feather (*Myriophyllum aquaticum*). The next two, established as 'artificial wetland' systems, consisted of alternating sections of open water and gravel planted with cumbungi. Of the last two trenches — controls without plants — one contained gravel and the second open water.

Along with the trench experiments, Mr Breen and Mr Chick conducted a series of glasshouse trials using gravel-filled buckets containing cumbungi and the common reed (*Phragmites australis*). Previous research had shown that the species had considerable potential, but it was difficult to study in large systems because the roots tended to puncture flexible lining materials, making water–nutrient balance measurements difficult.

Perhaps not surprisingly, the capacity of the trenches to remove nutrients increased as the plant cover increased. When well established, a number of the systems removed 90% of the input nitrogen load. As might be expected the open-water trenches showed the poorest results. The gravel-filled trenches performed well, the gravel acting as an extended gravel-bed filter that removed particulate solids. But, to date, the simulated wetland systems with alternating gravel and open water have shown the most promising performance. The routine results show that removal of BOD, nitrogen, and suspended solids approaches 90%.

According to the collaborators, this good performance appears related to the alternating zones within the systems, a combination that provides the most number of microsites for the aerobic and anaerobic

The 12 × 12-m pilot system at Kapooka Army Barracks, Wagga Wagga, nearing completion. The newly established plants are clubrushes (*Schoenoplectus validus*). When fully operational the system will treat 10 000 litres of primary settled sewage per day.

The experimental trenches at the University of Western Sydney, designed to receive some 400 000 litres of effluent per day.

bacteria essential for the conversion of organic nitrogen into a form that can be absorbed by plants or released into the air as nitrogen gas.

The trench systems routinely removed 40% of the phosphorus, and at times as much as 60–80%. The removal process involved chemical precipitation, bacterial action, plant uptake, and adsorption onto the gravel.

In studies carried out by the University, the treatment systems have achieved significantly greater reductions in bacterial populations than oxidation ponds and many chlorination systems. The artificial wetland trenches exhibited the greatest reduction — 99·9%.

Plants in the glasshouse experiments consistently took up a higher percentage of nitrogen and phosphorus than those in the trenches. The team put this down to the lower loading rates and the input flow arrangement used in the small-scale experiments: the latter was more conducive to root–effluent interaction than the horizontal-flow scheme used in the trench studies. Nevertheless, the success of the trench systems at Richmond has encouraged other authorities to examine the use of wetlands systems to treat waste-water.

For example, the University of Western Sydney's Water Research Laboratory is continuing its macrophyte research and collaborating on two separate wetlands projects — one with the Sydney Water Board and the Blue Mountains City Council to the north-west of Sydney and the other with the Byron Bay Shire Council on the northern coast of New South Wales. The latter project, which should be operational by midway through this year, will use a series of wetlands trenches and ponds in the final stage of a cleansing process that includes settlement and chemical treatments. Based on experience gained in the Richmond trials, the designers are using sub-surface inlet ports and a series of baffles to improve the way waste-water flows through the trenches and interacts with the root zone.

The 'vertical flow' alternative

Following the Richmond study, the CSIRO-Water Resources team at Griffith continued to focus on the development of a wetlands system that would treat effluent to an acceptable standard after only primary settlement of the sludge. As they examined more and more data, it became increasingly clear that performance differences were significantly linked to system hydrology.

It seemed that, in the trench systems, plant-root densities usually decrease with depth; as a result, waste-water moving along the bottom of the trench could largely by-pass the root zone. To make the best use of the nutrient 'stripping' qualities of swamp plants in the treatment process, a system must optimise the waste-water–root zone contact. The scientists believe that they have now developed such a system based on the vertical-flow principle illustrated on the next page.

Applications and benefits

Normally, effluent is treated in three stages. A primary treatment removes solids, usually by some form of settlement process. Conventional secondary and tertiary treatments remove the biochemical oxygen demand, nutrients, and bacteria associated with raw sewage to produce clear, odourless water with acceptable oxygen levels, but tend to have high capital and operating costs. A well-designed wetlands system can be a much cheaper alternative to the last two stages.

As mentioned in the main story, members of the research team are currently testing operational units of a vertical-flow system in different environmental conditions in New South Wales. As soon as practicable, they intend to install more operational units across Australia, so that they can test the performance in a wide range of climates and develop appropriate management strategies for harvesting.

They are also working out what size systems are suitable for populations in the hundreds and in the thousands. At the moment, they think the system will be limited to populations up to about 10 000. To treat waste from bigger populations would require installations covering very large areas. This virtually rules out the process as a solution for our big cities like Sydney where land is already in short supply — except perhaps for use by individual households that are still unsewered.

Nevertheless, should the system prove effective over the range of conditions tested, it has considerable potential for savings in Australia and for export earnings. A provisional assessment of this potential by Dr John Sale and Mr Alan Chick leads them to believe that the world market is very big indeed. The simplicity of its technology and its low establishment and maintenance costs will be big incentives. (The wetland treatment system should cost between 25 and 50% of the costs for conventional treatments producing discharge water of the same quality.)

As an example of the economic benefits involved, the scientists have calculated the savings for rural New South Wales, which they estimate has some 500 small communities that need new sewerage systems or their old ones upgraded. They reckon that if the wetlands system were adopted, over the first few years the lower maintenance and operating costs alone would save the State's ratepayers hundreds of millions of dollars.

Rural effluent: nobody wants it any more

Traditional ways of treating rural wastes are having to change. Take manure, for example. Yes, please take some manure. There's too much of it and the quality is just not what it was. World-wide, the old days of muck-spreading to simultaneously get rid of the effluent and fertilise the paddocks are coming to an end — fast. Most of the problem lies with the intensive production techniques used in the agricultural industries of Europe and the United States; their effluent is too concentrated to just dump on the paddocks untreated. Swamp macrophyte systems may offer a low-cost solution.

Although trench experiments with some rural effluents showed that the system could only cope with diluted effluents, the new vertical-flow design appears to be more efficient. Whether it can treat highly concentrated effluents has still to be tested.

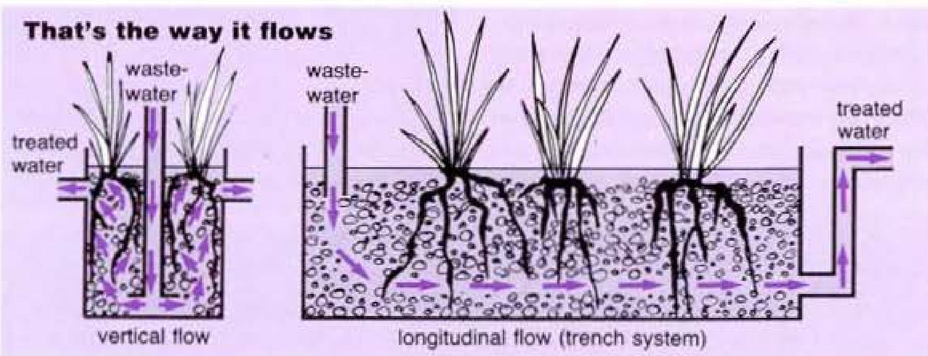
One thing is certain — the installation would need to be tailored to meet the demands of particular enterprises. A 100-sow piggery, for example, can produce about half a tonne of solid waste, contained in 7000 to 15 000 litres of liquid, per day.

The quantity of muck is not the only problem. These days it is often laced with heavy metals — cadmium, copper, and zinc — used as additives in animal food. Cadmium is a trace element in a feed that makes pigs retain water and gain weight quickly, copper is added because it improves digestion, while zinc is added to compensate for the deficiency induced by the copper. In parts of Europe these metals have leached from manure spread onto fields and moved into domestic water supplies, making the water unfit for human consumption. (Some of the CSIRO research at Griffith, carried out largely by Dr Kathleen Bowmer, indicates that the vertical-flow systems have considerable potential for immobilising these heavy metals.)

We can be grateful that, in Australia, our extensive farming techniques have insulated us from the worst, but trends indicate that we're catching up. In the very near future we'll need to develop cheap, environmentally sound effluent-treatment systems that can cope with rural wastes our grandparents would look at in disbelief.

Detoxification of effluents in a macrophyte treatment system. K.H. Bowmer. *Water Research*, 1985, **19**, 57–62.

Rhizosphere oxygenation by *Typha domingensis* pers. in miniature artificial wetland filters used for metal removal from waste-waters. J.S. Dunbabin, J. Pokorny, and K.H. Bowmer. *Aquatic Botany*, 1988, **29**, 303–17.



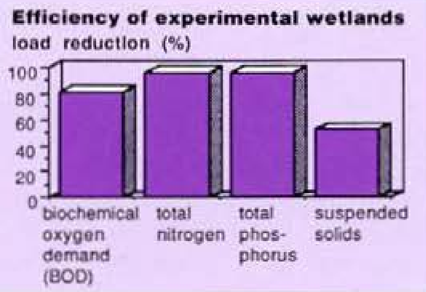
The patented vertical-flow design ensures that the waste-water comes in contact with the plant roots as it moves up gradually through the gravel. By contrast, in the trench design, waste-water may by-pass the root-zone.

In more than 3 years of glasshouse trials, the system has sustained removal rates of more than 95% of the phosphorus and nitrogen supplied in the form of primary settled sewage (see the chart). Detailed examinations of the fate of these nutrients reveal that the largest proportion is taken up by the plants, although, as the diagram on page 19 indicates, significant quantities of nitrogen are lost to the atmosphere.

The question of whether the system can keep on removing nutrients at this level of efficiency without some form of management is still being addressed. Overseas experience suggests that harvesting the emergent plants in wetlands systems is not essential to sustain the process, whereas Australian work indicates that harvesting may be necessary, particularly if the nutrient loading is high and the wetlands are responsible for the major part of the waste-water treatment. Although the best possible approach has yet to be determined, preliminary research shows that it will be possible to develop a suitable harvesting pattern that removes the nutrients without decreasing plant vigour.

As *Ecos* goes to press, an Australian patent is being finalised, so we cannot reveal precise design details. However, the scientists say that, as well as encouraging the effluent to permeate through the root zone, the system is virtually flood-proof, provides no free-standing water for pests such as mosquitoes, is odourless, and will tolerate shock loads of nutrients. They've calculated that construction and maintenance costs will be low relative to those of more conventional processes. And, once established, the swamp plants also offer an interesting addition to the landscape — a thriving community of Australian natives.

David Brett



Typical results from the vertical-flow system using clubrushes (*Schoenoplectus validus*), effluent from primary settled sewage (concentrations typically 2 mg total nitrogen and 0·35 mg total phosphorus per litre), and a retention time of 5 days.

More about the topic

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Treatment of piggery effluent by an aquatic plant filter. C.M. Finlayson, A.J. Chick, I. von Oertsen, and D.S. Mitchell. *Biological Wastes*, 1987, **19**, 179–96.

Sewage treatment using aquatic plants and artificial wetlands. D.J. Roser, S.A. McKersie, P.J. Fisher, P.F. Breen, and H.J. Bavor. *Water*, 1987, **14**, 20–24.

An assessment of a natural wetland receiving sewage effluent. C.M. Finlayson, P. Cullen, D.S. Mitchell, and A.J. Chick. *Australian Journal of Ecology*, 1986, **11**, 33–47.

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The potential for wastewater treatment by aquatic plants in Australia. D.S. Mitchell. *Water*, 1978, **5**, 15–17.