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on

Wetland Systems

for

Wastewater Treatment

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Using Submergent Macrophytes for Domestic Greywater Treatment

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Abstract

Aquatic plants offer a technically simple, low cost, energy-efficient method of treating domestic greywater. Aquatic plant systems require little technical back-up and are easy to maintain. Certain rooted aquatic plants have bacteriocidal properties and the ability to breakdown chemical pollutants, and submerged aquatics are also important as oxygenators.

Reeds and rushes take up and store nutrients themselves, provide a growing area for micro-organisms, stimulate the soil activity by root excretions and reduce the volume of effluent by transpiration. Effluent passes through various stages and the wastewater is gradually stripped of nutrients and pollutants.

However, conventional reedbed systems are little more than monocultures of *Phragmites*, *Baumea*, Water Hyacinth, *Typha* or *Schoenoplectus*. Pond systems, employing a wider range of species, is a means to recycle more nutrients, improve treatment potential and mirror natural ecosystems - in ways to sustain the ecosystem.

Species of *Triglochin*, commonly known as water ribbons throughout coastal Australia, are fast growing submergent macrophytes which seem to be adapted to high nutrient concentrations. In Western Australia, *Triglochin huegelii* is mainly a submergent plant but its leaves tend to float on the surface in shallow waterways and it has been found seasonally in some ephemeral swamps and lakes. As water recedes, the leaves become emergent.

Initial studies using *Triglochin huegelii* in wastewater treatment experiments has shown that *Triglochin* has consistently more nitrogen and phosphorus than *Schoenoplectus validus*, an emergent commonly used for wastewater nutrient stripping, in all parts of the plant - leaves, tubers and roots. In some cases, such as in the leaves, twice as much nitrogen and one and a half times more phosphorus is assimilated in the *Triglochin* tissue.

One prediction is that *Triglochin huegelii* will remove nitrogen and phosphorus at a greater rate than many other types of aquatic macrophytes. The implication is that instead of only planting the perimeter of lagoons, artificial wetlands and constructed basins we should be planting the bulk of the waterway with submergent species such as *Triglochin spp* which are far more effective in stripping nutrients than emergents currently used for that purpose.

1.0 Introduction

The increasing extent of residential and commercial development in the outer Perth metropolitan area has resulted in demands for high water quality before discharge into watercourses or for reuse applications. Additionally, the rising costs of building, maintaining or upgrading sewage and wastewater treatment plants is of increasing concern to the public and health and water authorities in this state. An effective greywater reuse system would reduce the need for increased capital expenditure on the building and use of municipal treatment systems.

Accordingly, in recent years, there has been increased interest in alternative and innovative technologies, with the aim of developing low cost, low maintenance and efficient treatment of wastewaters. Water reuse is becoming more common throughout the world, although mostly at the municipal level, where it is used to water parks, golf courses and other landscapes. Greywater reuse from domestic houses has received very little attention.

Good treatment of greywater is especially important in areas which have soils of low infiltration rates, are close to natural waterways or have high ground water tables. In small communities where liquid waste disposal is difficult and/or expensive, recycling can be a cost effective option. A typical family could expect water savings up to 50%, but usually less than 35%, if all greywater was treated and recycled on site.

Instead of consuming, polluting and discharging water, we can purify, reclaim and reuse it. There is no hope for creating a partnership with nature without sustainable systems. Technologies and techniques, both chemical and biological, employed in nutrient removal, now make it possible to remove 90 to 99% of all organic and inorganic pollutants, and improvements on these figures are continually being made.

Aquatic plants offer a technically simple, low cost, energy-efficient method of treating greywater. Aquatic plant systems require little technical back-up and are easy to maintain. Certain rooted aquatic plants have bacteriocidal properties and the ability to breakdown chemical pollutants, while submerged aquatics are important as oxygenators. Effluent passes through various stages and the wastewater is gradually stripped of nutrients and pollutants.

The quality of treated greywater effluent primarily depends on the duration of the biological and chemical treatment of the wastewater or upon the detention time (usually in days) as the greywater is undergoing treatment. Treatment of wastewater depends on factors such as system design, the chemistry of the plant root-water-sediment environment, plant uptake, available carbon (for microbe activity), nutrient volatilisation (e.g. ammonia) and type of substrate.

Some greywater also contains human pathogenic organisms and may pose a health risk. Greywater, in such cases, must be treated to minimise this risk, or disposed in such a way to prohibit direct human contact. Furthermore, greywater, while containing nutrients essential to plant growth, can cause environmental problems if it is discharged into natural waterways.

It is the soluble reactive phosphate which causes algal blooms, but not organically bound phosphorus. This is important as many Australian plants are sensitive to high levels of phosphorus, and therefore its removal is crucial to the growth of these types of plants.

The aim of any system, including those related to wastewater, should be the complete recycling and reuse of all resources in the environment. We need to design systems that maximise the biomass productivity, such that a range of useful products such as food, fodder and materials are produced, while also taking responsibility for the effects of our wastes on the environment.

2.0 Greywater Treatment

Wetland plants are ideal candidates for wastewater treatment. They possess special characteristics, which are briefly discussed in the next section, that allow them to grow in a water environment.

All three biodegradation processes, namely aerobic, anoxic and anaerobic, are found in wetlands and thus are applicable in greywater treatment. Aquatic plants remove pollutants by directly assimilating them into their tissue and by providing a suitable environment for micro-organisms to transform pollutants and reduce their concentrations. Such biochemical and physico-chemical processes include nitrification, denitrification and ammonia volatilisation.

Wastewater recycling is in its infancy in Australia. There are strong community concerns that wastewater should be reused, rather than discharged into rivers or the ocean. However, considerable improvements would be needed on current individual household systems to achieve acceptable public health and environmental outcomes in urban areas.

Most of the research in wastewater and greywater systems has been too narrow in focus and, in many cases, environmentally-unfriendly, costly and difficult to set-up and maintain. Other natural systems, based on sustainable practices, should be the focus and direction for future work.

Current research has been centred on using either vertical or horizontal flow reed systems, or some combination of these two. Due to their efficient soil aeration, the vertical flow beds require much less area for nitrification and removal of organic compounds than horizontal flow beds. As vertical flow beds show very poor denitrification rates, horizontal flow beds can be added as a second stage for denitrification. An aerobic environment followed by a mostly anaerobic one should enhance nitrification and subsequent denitrification to remove most of the nitrogen from wastewater.

Alternating systems for greywater treatment seem to have much higher nitrification potential than beds which are continuously fed. The ammonia adsorbed can be nitrified during the drying period. The nitrate so formed is washed out in the next loading cycle and enables new ammonia fixation. Periodic resting of the beds or tanks improves the overall efficiency of the treatment.

Untreated greywater, especially kept in storage, would quickly turn septic and emit unpleasant odours, and clog pumps and irrigation systems. Kitchen wastewater is potentially the poorest quality greywater, although greywater also contains soaps, detergents, hair, lint and bacteria, as well as other materials which include a wide range of foodstuffs, cooking oils and grease. All of these substances promote the presence and growth of bacteria and other pathogens.

Greywater should be reused immediately, rather than the current situation whereby a settling or surge tank is employed to hold greywater before being passed to the infiltration area. Holding greywater for extended times increases the growth of potential pathogens.

Furthermore, most greywater disposal methods advocate subsurface irrigation. However, most pathogens are easily killed by aeration so it makes sense to irrigate the top 300 mm or so, rather than deeper below the surface.

Greywater and wastewater is mainly treated in reed beds. Reed beds are normally trenches where all water is kept subsurface - to minimise the risk of mosquito breeding and unpleasant odours. However, ponds, rather than trenches, may be more beneficial in wastewater treatment. Ponds contain a variety of organisms and can be stocked with macrophytes and algae. Algae are important in that they produce a strong pH shift towards alkaline conditions which favours ammonia evaporation and nitrification.

The high pH also causes phosphate mineralisation as it reduces phosphorus mobility in solution and can provide a 100% kill of *E. coli* and presumably most other pathogenic organisms.

The greatest benefit of the pond system is its rapid response to shock loading events. As bacteria and algae have short generation times, they are able to adjust their population levels according to the loading received. Macrophytes, too, have a broader function than simply supplying a large surface area for micro-organisms.

The size of ponds and infiltration areas must be calculated to reflect the amount of nutrient intake (number of people), the seasonal temperature variations and the characteristics of the plants themselves (some species die back in winter). While some researchers may suggest that pond systems require 5 to 8 m^2 per person, I believe it is possible that only 1 m^2 per person is necessary when a more holistic approach is taken to wastewater treatment.

Ponds will also allow the natural water levels in the system to be changed. In this way the life cycle of plants is enhanced, plant diversity is encouraged and a greater range of plants, with their special conditions for growth, can be maintained.

3.0 Types of Plants used in Greywater Treatment

A large number of indigenous and exotic wetland plants have been used in trials of wastewater treatment. Some have been more successful than others, but all seem well suited to tasks such as nutrient stripping.

3.1 Capabilities of Wetland Plants

Wetland plants have a high rate of growth and high productivity. This requires a high nutrient supply, and where nutrients are not readily available, such as in natural ecosystems, these plants can recycle their nutrients by translocating them from storage areas to areas of new growth and repair.

Many of these wetland plants can take up excess nutrients and store them for later use. This "luxury" uptake enables plants to continue to grow when nutrients, or some other factor in the environment, is limiting.

Plant uptake is a major nutrient removal mechanism in wastewater treatment systems. Consequently, if plants are to be used in a system, then the wastewater-rootzone contact must be optimised.

Adequate contact between water, sediments and plants must be maintained for optimal wastewater treatment. In emergent species, such as *Schoenoplectus validus*, only the roots, rhizomes and leaf base are in direct contact with the water. In submergents, such as *Triglochin heugelii*, all of the plant can be in direct contact with the wastewater, potentially enabling greater nutrient removal.

These types of plants, and others such as *Typha, Phragmites* and *Scirpus,* offer a large surface area in the water column and substrate (soil) for microbiological growth.

Atmospheric oxygen is also transported to the roots, where an aerobic microbial film, called the rhizosphere, forms around the roots. Surrounding this are anoxic and anaerobic films because the oxygen available through the root system is limited.

Many microbes require the aerobic conditions around the rhizosphere, and the plants often utilise the metabolites these micro-organisms (mainly bacteria) produce. Apart from oxygen, plants exude organic carbon and other substances to enhance the action of the rhizosphere organisms.

Besides rocks and soils, roots provide the all-important surfaces on which bacteria collect and grow. Stems and leaves act as natural aerators to funnel oxygen to the roots, shelter the water from wind, and shade the aquatic environment, preventing the overgrowth of algae. Symbiosis ensures: marsh plants absorb the metabolites produced by the bacterial degradation of the organic compounds while the microbes exploit the metabolites released from the plant roots. In essence, both use each other's wastes.

Conventional reedbed systems, the most common, small scale methods for wastewater treatment, are little more than monocultures of *Phragmites, Baumea,* Water Hyacinth, *Typha* or *Schoenoplectus.* Pond systems employing a wider range of species is a means to recycle more nutrients, improve treatment potential and mirror natural ecosystems - in ways to sustain the ecosystem.

By using various reeds, rushes and submergents, such as *Scirpus* and *Phragmites spp,* in a system, many inorganic and organic materials will be absorbed and some flocculation and settling of colloidal substances will occur. Other plants such as Iris and *Typha spp* have been shown to actively destroy pathogens including *Salmonella.* Many of the health concerns of authorities could be addressed by simply designing better treatment systems.

3.2 *Triglochin* characteristics

Species of *Triglochin* are perennial, rhizomatous, freshwater emergents which form monospecific populations of primarily vegetative shoots. They usually have large, fleshy, flattened leaves, the length of which depends on the degree of flooding. Shoots produce new leaves every few weeks.

Triglochin shows no seasonal senescence, with growth occurring throughout the winter period, and because of its high protein content, comparable to lucerne, it could have potential as a fodder source.

Some consideration needs to be made about the water regime and its possible effect on the efficiency of particular macrophytes in waste treatment processes. Whether a species' optimal performance occurs at a given depth or under a particular water regime (including the depth, duration and rate of inundation and drying phases) is largely unknown.

By altering the water level in a system, flowering, seed production, seed dispersal and seedling establishment are often affected. Stabilised water levels reduce seed dispersal and interrupt the life cycle of the plant. Changing water levels will also affect the amount of aeration and hence nitrification and denitrification which occurs in the system. *Triglochin* appears to respond to a changing water regime during its life cycle, by adjusting its height and diameter according to depth, and with the development and lengthening of its leaves.

As water level changes, so does the availability of above and below-ground resources such as inorganic carbon, oxygen, light and nutrients. Species of *Triglochin* may use dissolved carbon and nutrients directly from the water, whereas other macrophytes usually rely upon gaseous exchange with the atmosphere and other nutrients from sediments.

Triglochin species may need less energy to mobilise resources because they can access resources from below as well as above the water, as indicated by the thin cuticle of their spongy leaves.

Nutrients absorbed during growth are translocated to the below-ground storage organs (tubers). Later, these nutrients are mobilised upwards for use by the young shoots in the next growing period. Reallocation of biomass between compartments is essential for surviving water level changes. Species that can maintain allocation to shoots without an adverse effect of total or below-ground mass are at a distinct advantage.

4.0 Methods and Materials for Nutrient Removal Studies

Twelve identical 200 L tanks, as shown in figures 1 and 2, were set up such that four different tank plantings were repeated three times. The tanks contained 300 mm of 20 mm stone, 100 mm washed sand and 400 mm water, with one of the following:

1. *Triglochin heugelii* only. (Designated "Th" in the tables).
2. *Schoenoplectus validus* only. (Designated "Sv" in the tables).
3. *Triglochin heugelii* and *Schoenoplectus validus* combined. ("T/S" in tables).
4. No plants - as the control.

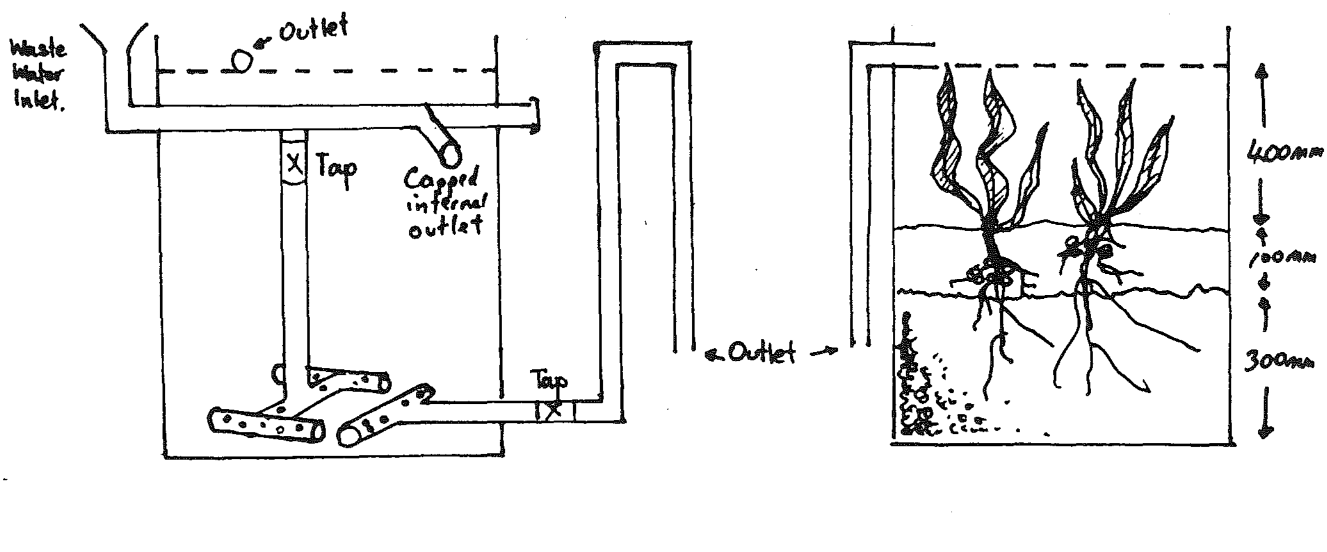

Figure 1 Cross-section of a typical tank.

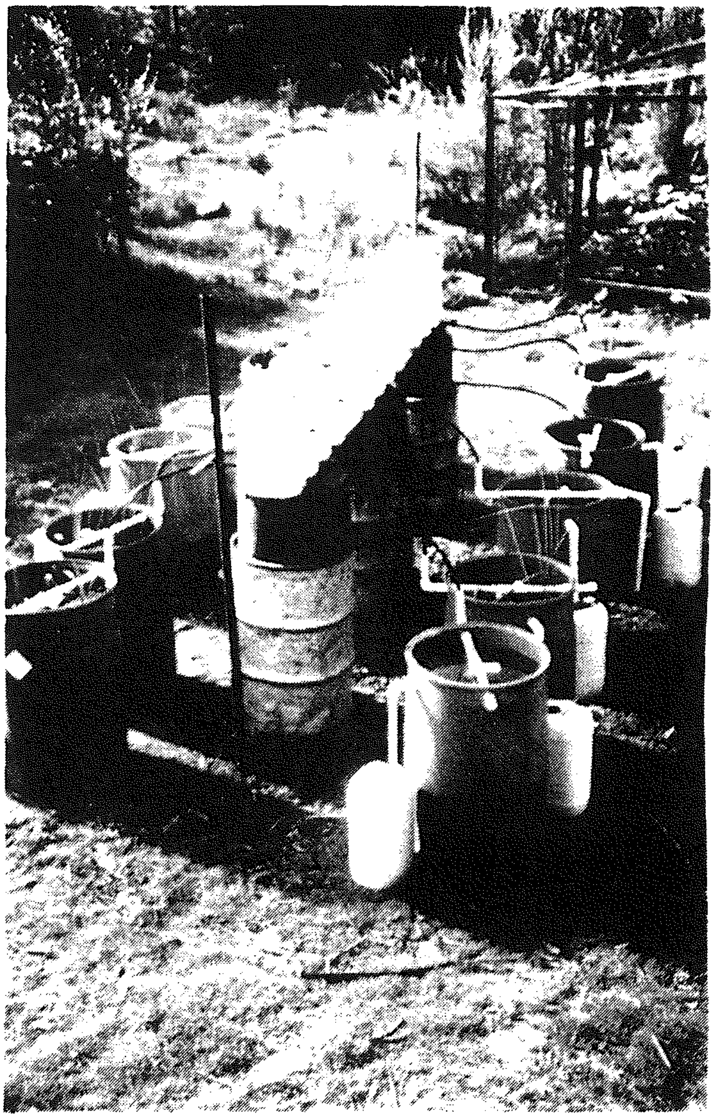

Figure 2 The arrangement of the experimental tanks.

An initial nutrient amount of 10 L of 19.60 mg/L nitrate and 9.90 mg/L phosphate (as KNO_3 and NaH_2PO_4 respectively) was added to each tank. Total initial nitrate in each tank = 196 mg and total initial phosphate in each tank = 99 mg. These levels are typically found in domestic greywater.

Each day, 10 L of scheme water was added to every tank. Water flowed from the bottom upwards (vertical flow) and was collected, sampled and tested after it passed through the overflow outlet. Samples were tested for both nitrate and phosphate concentration using a Hach DR 2000 Spectrophotometer.

The duration of this investigation was thirty days. The results are shown in table 4. Samples of plant tissue were analysed for total Kjeldhal nitrogen and total phosphorus before any nutrient was added and at the completion of the investigation. Two samples of algae, which grew during the experiment, were collected from tanks and also analysed in this way. Tables 1, 2 and 3 contain this data and interpretations of it.

5.0 Results and Discussion

Analysis of the main plant parts, as shown in table 1, indicate that *Triglochin* has more nitrogen and phosphorus than corresponding parts in *Schoenoplectus*. In some cases, such as in the leaves, twice as much nitrogen and one and a half times more phosphorus is assimilated in the *Triglochin* tissue.

Species and part	Before expt.		After expt.	
	Average N mg/g dry mass	Average P mg/g dry mass	Average N mg/g dry mass	Average P mg/g dry mass
Triglochin leaf	20.80	2.60	25.2	3.80
root	10.90	5.20	11.70	9.13
tuber	7.70	4.24	6.60	9.18
Schoenoplectus leaf	9.65	1.56	13.50	2.65
root	5.85	0.67	6.35	1.45
rhizome	5.10	1.79	4.55	2.48

Table 1 Nitrogen and phosphorus content of plants before and after initial experiment.

At the end of the first study, both *Triglochin* and *Schoenoplectus* generally increased their levels of total nitrogen and phosphorus in their tissues. In both plants, the relative amount of nitrogen in the tubers (*Triglochin*) and rhizomes (*Schoenoplectus*) decreased, most probably as it was translocated to growing leaf regions.

The total nitrogen and phosphorus levels were calculated and shown in table 2. Here, the nutrient levels in each tissue were added, the difference in initial nutrient content and final content was determined and the percentage increase of each nutrient was calculated. Clearly *Triglochin* has gained more nitrogen and far more phosphorus than *Schoenoplectus*.

Species	Initial N	Final N	Mass gain	%N increase	Initial P	Final P	Mass gain	%P increase
Triglochin	39.4	43.5	4.1	11	12.04	22.11	10.07	84
Schoenoplectus	20.6	24.4	3.8	18	4.02	6.58	2.56	63

Table 2 Summay of nutrient totals in both species. Mass units are expressed as milligram of nutrient per gram dry mass.

Table 3 compares the increase, or decrease, of total nitrogen and phosphorus in each plant. *Schoenoplectus* seems to have the greatest increase in nutrient content, except for phosphorus in the rhizomes compared to the tubers of *Triglochin*. *Schoenoplectus* may have greater ability to store more nutrient, although the amount stored per gram of dry mass is much less than *Triglochin*.

Another interesting observation, as shown in table 4, is that both plants store different nutrients to different degrees in different parts. For example, nitrogen is primarily stored in the leaves of *Triglochin* and *Schoenoplectus*, while phosphorus is stored in the below-ground root, tuber or rhizomes regions.

Preliminary investigation suggests that *Triglochin* shifted nitrogen upwards to above-ground parts and phosphorus downwards to below-ground parts.

Plant species and part		% N increase or decrease	% P increase or decrease
Triglochin	leaf	21.15	45.97
	root	7.34	75.58
	tuber	- 14.29	116.51
Schoenoplectus	leaf	39.90	70.10
	root	8.55	118.05
	rhizome	- 10.78	38.27

Table 3 Amount of nutrient increase or decrease during experiment duration.

Species	Before expt.		After expt.	
	% Nitrogen	% Phosphorus	% Nitrogen	% Phosphorus
Triglochin leaf	53	22	58	17
root and tuber	47	78	42	83
Schoenoplectus leaf	47	39	55	40
root and rhizome	53	61	45	60

Table 4 The relative amounts of nitrogen and phosphorus in above and below ground plant tissues.

The amount of phosphorus in all *Schoenoplectus* parts seems to be reasonably constant, while the nitrogen is shifted from below-ground parts to new growth areas above-ground.

Table 5 shows the results of the thirty day experiment. As predicted, both *Triglochin* and *Schoenoplectus* have absorbed, utilised or stored some nitrate and phosphate. Individual plantings of *Triglochin*, for example, have taken in proportionally more nitrogen than *Schoenoplectus*. Both types of plants have absorbed a similar amount of phosphorus, which is more than twice the amount of nitrogen. *Schoenoplectus* had slightly better absorption of phosphorus than *Triglochin*, although on the small sample size there would be little to statistically distinguish them.

	Th N	Th P	Sv N	Sv P	T/S N	T/S P	Cont N	Cont P
Collected	137.87	25.46	146.50	23.52	152.53	53.62	147.95	48.77
Retained	58.13	73.54	49.5	75.48	43.47	45.38	48.05	50.23
Absorbed by plant	10.09	23.31	1.45	25.25	-4.58	-4.85	-	-

Table 5 Amount of nitrate and phosphate absorbed by plants. All units mg.

Note: The values for absorption by plant is calculated by subtracting the amount estimated to be retained in the tank minus the amount retained by the control set-ups.

What is surprising, and which will need further investigation, is that there has been less absorption of both nitrogen and phosphorus when both plants are grown together - about the same as the control set-ups. This suggests that there could be some inhibiting interaction between the plants, or some unknown factor may be responsible for these anomalous results.

The control tanks, with no plants, still retained a high level of nitrogen and phosphorus, suggesting that these nutrients could have been adsorbed onto the substrate surface or been metabolised by various types of bacteria in the substrate layer.

Some portion of the nitrogen load that cannot be accounted for in the plant material, soil medium, or effluent outflow can be assumed to have been lost as gaseous nitrogen - produced by microbial metabolism in the anaerobic section at the bottom of the tank.

Cooke (1994) has found that 60 - 70% of nitrate in wastewater samples was denitrified, 25 - 35% was converted to ammonium ions and only 5 - 10% was assimilated. This low amount of nitrogen assimilation is supported by this experiment where about 5% of nitrogen was believed to be taken up by *Triglochin*, but only 1% by *Schoenoplectus*.

While nitrate can be removed by denitrification or by plant uptake, phosphorus is more difficult to remove. It doesn't form a gaseous phase, unlike nitrogen, so the phosphorus must be stored in plant tissue.

Most phosphorus is believed to be stored in the substrate layer, rather than in plant tissue. This is shown in the initial studies of *Triglochin* where more than 50% of phosphate in the control tanks had been removed after 30 days, presumably by adsorption, whereas only 25% of nitrogen was adsorbed or not collected in the effluent.

More phosphorus (than the nitrogen) seems to be taken up by the plants. Table 5 shows that *Triglochin* may have absorbed an average of 20 mg of phosphorus, which is about the same as *Schoenoplectus*. This is supported by the analysis of plant tissue in table 2, where a far greater increase in phosphorus was recorded.

Tanks with plants also grew filamentous algae. Analysis of the algae showed that some nitrogen and phosphorus was assimilated into the tissue. Algae can be used as part of an ecosystem pond because they purify efficiently even during cloudy, winter conditions. The difficulty in most other systems is how the algae can be controlled and harvested.

It can be seen that changes in the amount of nitrogen and phosphorus in plant parts are directly related to changes in biomass and to nutrient reallocation within the plant. For example, a decrease in *Triglochin* tuber mass is offset by an increase in shoot mass. However, this re-allocation alone cannot account for the total increase in nitrogen and phosphorus in other plant regions.

Furthermore, it hasn't been established whether nutrient storage primarily occurs below-ground in shallow water and above-ground in deep water, or vice versa. I suspect that the *Triglochin* tubers are organs which gives this species added tolerance to depth. Additional studies may help to clarify this.

Finally, results so far do suggest that the submergent *Triglochin* is an effective nutrient stripping plant. For example, table 2 shows that *Triglochin* gains more total nitrogen and phosphorus in its tissues than *Schoenoplectus*. The implication is that instead of only planting the perimeter of lagoons, artificial wetlands and constructed basins we should be planting the bulk of the waterway with submergent species such as *Triglochin spp* which are far more effective in stripping nutrients than emergents currently used for that purpose.

6.0 Future Potential of Greywater Treatment

The next phase of research with these plants will be to pass domestic greywater through the tanks. Ten litres of greywater, collected in a settling tank, will be added to each tank every second or third day. Analysis of BOD, nitrate, phosphate, ammonium and bacteria for both influent and effluent will indicate whether submergent plants, such as *Triglochin*, contribute to other aspects of greywater treatment, besides nitrate and phosphate removal.

Typical volumes of domestic greywater has been estimated by Jepperson and Solley (1994) at 400 L per day per household. This is much less than the 180 L per day per person (720 L for a family of four) estimated by the Public Health Department of Western Australia. To treat this volume on a continual basis would require a very large treatment system to guarantee minimum nutrient loss or leaching from the system. The size needed for such treatment will be the focus for future endeavours.

What is not taken up by plants or removed by other means would be a potential pollution problem. It is important that as much nutrient as possible is removed from the system.

To accomplish total nutrient and pathogen removal would require the design of better treatment systems. Considerations for the design of the "best treatment" system would, in turn, lead to the idea of a holistic, integrated design - something Wang (1991) calls an ecosystem pond.

Wang's ecosystem ponds consist of various food chains formed from fish farming, duck and geese raising, and several macrophytes growing together. The biological, chemical and physical processes, which occur in the ecoponds, result in efficient removal of nutrients, and disease organisms, while reclaiming them in forms of aquatic plants, fish, duck and geese as recoverable resources.

Developing an ecosystem approach, with consideration of all components of the ecosystem, results in yields five times the conventional rates of fish farms (Chan, 1993).

Ecosystem ponds imitate the natural processes, but enhance them with appropriate technology and know-how. We need to look to Mother Nature who is performing this simple act of recycling all the time.

Greywater, after treatment, would be most suitable for aquaculture activities. Water could be piped to trenches or beds where plants could be grown. Alternatively, ponds which contain a variety of plants and animals could be set up. Aquaculture has huge potential as the productivity of water-based food production can be far greater than land-based production systems.

Finally, we must consider sustainable solutions to our growing waste problem. Conventional sewage treatment systems mostly convert organic matter into inorganic ones and shift the pollution problem elsewhere. We need to design systems that mimic natural ecosystems, and yet are economical and functional.

7.0 References

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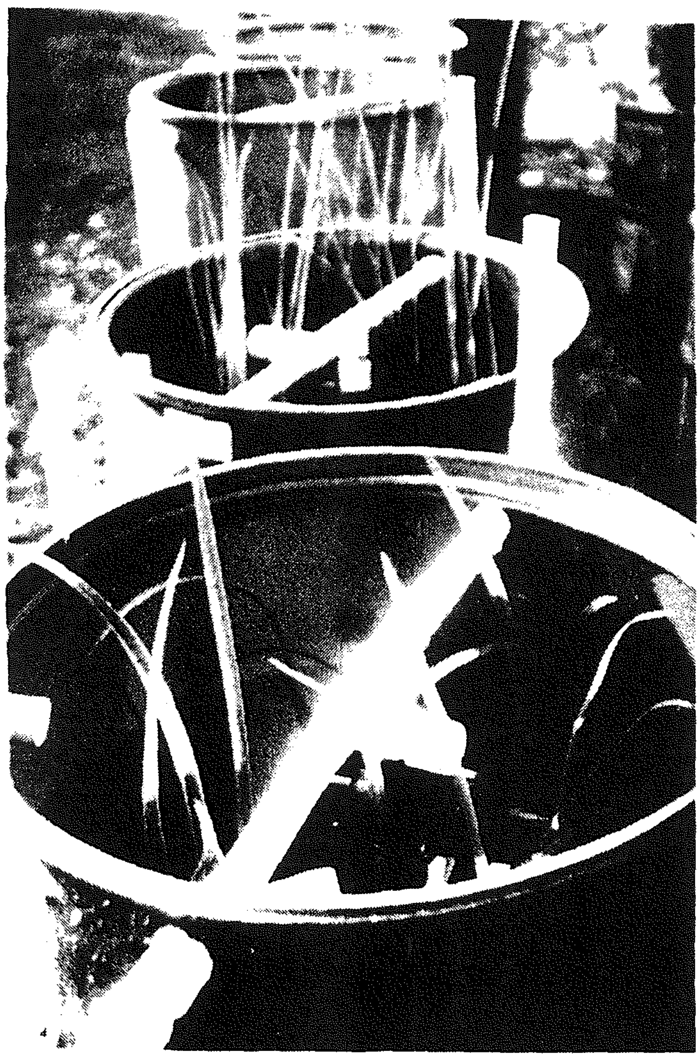

Figure 3 *Triglochin* and *Schoenoplectus* in the experimental tanks.