

The filter system for tertiary treatment of sewage effluent by land application – its performance in a subtropical environment

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Abstract FILTER is an innovative, CSIRO developed system for treating effluent using high rate land application and subsequent effluent recapture via a closely spaced, subsurface drainage network. We report on the summer performance of a FILTER system established in a subtropical environment on a relatively impermeable swelling clay soil underlain by a deep regional water table. Using secondary treated sewage effluent, the FILTER system produced effluent of tertiary nutrient standards (≤ 5 mg/L TN; ≤ 1 mg/L TP), with salinity levels suitable for subsequent irrigation reuse ($EC \leq 2.5$ dS/m). Removal of faecal coliforms was considerably less effective. The hydraulic loading rate achieved was about two and a half times larger than conventional irrigation demand, but this was associated with high deep percolation losses (*c* 3 mm/day). Comparisons are made with the original FILTER system developed and tested by Jayawardane *et al.* in temperate Australia. Suggestions are made for modifications to, and further testing of FILTER in a subtropical environment.

Keywords FILTER; effluent; land application; drainage; tertiary treatment; nutrients; pathogens; salinity

Introduction

Local authorities in Australia are faced with increasing regulatory pressure to substantially reduce the nutrient levels in their secondary treated sewage effluent which is predominantly discharged to waterways. The main options available are: increased treatment at the Sewage Treatment Plant (e.g. BNR technology), irrigation of effluent (especially on agricultural land), high rate land renovation, and effluent polishing through artificial wetlands.

For capital cities with large treatment plants and limited access to irrigable land, upgrading to BNR, or a similar engineering solution is probably inevitable. In rural communities traditional irrigation schemes are a favoured option, but large wet weather storages are usually required in Australia. Alternatively, wetlands can be used, but have hydraulic storage problems in wet weather or periods of low evaporation. Other problems include hydraulic short-circuiting via preferred pathways, and a limited capability of reducing nutrients (and pathogens) from relatively high strength secondary treated effluent (Reed *et al.*, 1995).

To overcome the deficiencies in irrigation and wetland systems, the **FILTER** (Filtration and Irrigated cropping for Land Treatment and Effluent Reuse) technique was developed by CSIRO for treatment and reuse of secondary sewage effluent (Jayawardane, 1995). The FILTER technique combines reuse by intensive annual cropping with filtration through the soil to a sub-surface drainage system. High hydraulic loading can occur in periods of both low and high evaporative demand, substantially reducing the need for storage volumes. FILTER has been successfully tested in southern Australia (Jayawardane *et al.* 1997) and is being further tested at a semi commercial scale.

Because of the wide differences in soil types, effluent compositions and climates in Australia, it was considered important to test the FILTER concept in biophysical settings different to one in which it was developed (a low rainfall, Mediterranean climate, inland

irrigation area underlain with a shallow regional water table at Griffith, New South Wales). Consequently, an experimental FILTER system has been established in the subtropical environment of south east Queensland on a cracking clay soil with a deep (> 30m) regional water table.

In this paper we describe the design and operation concepts behind FILTER, describe the installation of FILTER on the Gatton campus of the University of Queensland, and present some results from the first (summer) season of operation.

Methods

Description of FILTER

FILTER uses a system of flood irrigation and subsurface agricultural drains to temporarily store secondary treated effluent. This strips out nutrients, pathogens, suspended solids and BOD using a combination of oxidation, reduction (i.e. denitrification) and soil adsorption (Figure 1). The quality of the subsequent treated effluent (≤ 5 mg/L N and ≤ 0.5 mg/L P) is usually of equal or better quality than BNR treated effluent, and can be licensed for discharge to surface water bodies (Jayawardane and Blackwell, 1996).

It operates on an approximately fortnightly cycle, where effluent is applied (100 mm to 150 mm), followed by a 1–2 day post irrigation equilibration period and an 8–10 day pumping period as effluent slowly passes through the soil to 1.0m deep agricultural drains and collection sump, followed by a 1–2 day post pumping equilibration period. The cycle is then repeated. The subsurface drainage system provides suitable soil conditions for crop growth even during heavy rainfall and low evapotranspiration periods.

In December 1998 we established the FILTER system in the grounds of Gatton Campus (University of Queensland) adjacent to the university's 80 ML/yr (trickling filter) sewage treatment plant. The soil was a self-mulching black clay (Vertisol) to a depth of 100 cm, followed by a 80 cm layer of sandy clay loam, and a 20 cm transitional clay layer. A *slowly permeable* grey clay layer occurs at 200 cm, which provides a restriction to deep drainage. The regional water table is at least 30m below the soil surface.

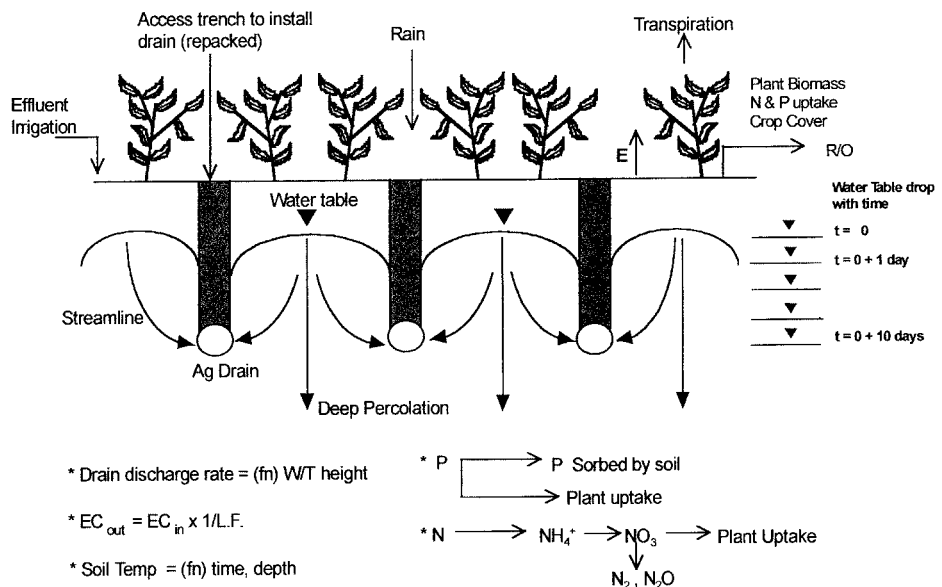


Figure 1 Schematic of the processes which occur during a typical FILTER cycle

Construction technique at Gatton

The design we chose for FILTER at Gatton was for two (2) irrigation bays, 200 m long \times 30 m wide which are irrigated with secondary treated effluent (≤ 30 mg/L N; 6 mg/L P) from a 4 ML effluent lagoon. Plastic agricultural drains (100 m diameter with geotextile sock) were installed at a depth of 1.5 m on a 10 m spacing using a backhoe. The slope of the agricultural drain was 0.25%.

A collection cross drain was installed at 2 m depth on the southern boundary of each bay to collect drainage from the 1.5 m agricultural drains. Treated effluent in the cross drain collects in 3 m deep concrete sumps. To minimise lateral leakage, a 200 μ m thick polythene perimeter curtain was installed to a depth of 2.5 m around each bay. A 50 cm high bund wall on the surface was constructed to contain the irrigation water. Bays were then cross ripped to 100 cm to create macroporosity and the soil surface laser levelled to a grade of 1 in 4,000.

Construction of the FILTER bays was completed in December 1998 (mid summer), grain sorghum was planted in mid January 1999 and effluent irrigation commenced on 15th March 1999. Secondary treated effluent was applied on a standard **14 day** cycle as well as a **7 day** cycle to maximise the number of times the Drainable Porosity was filled and emptied per cropping season. Using a system of trial and error we adopted a 150 mm and 75 mm effluent application for the 14 day and 7 day bays respectively. This compares with 100 mm per 14 days used by Jayawardane *et al.* (1997).

Measurements

Volumes of applied effluent to each bay and treated effluent pumped from each sump were measured using water meters connected to a Campbell Scientific CR10X data logger. Composite samples of effluent were collected from capillary bleed lines attached to the distribution pipework, and refrigerated on site. Samples were analysed for oxidised-N, Total Kjeldahl N, total-P, orthophosphate-P, pH, chloride and electrical conductivity using standard methods described in APHA (1995). Biological analysis included BOD and thermo-tolerant coliforms and these were done within 24 hours of collecting the effluent/drainage samples using standard methods (APHA 1995).

The water table in each bay was measured in an extra “dummy” agricultural drain using a Dataflow pressure transducer and logger. Rainfall and other climatic variables were recorded at the nearby University weather station.

Results and discussion

Hydrological performance

Total effluent applied is similar (580–600 mm) for both bays as is the amount of drainage water (150–165 mm). This result is expected as the irrigation depth applied in the 14 day cycle (150 mm) was twice that applied in the 7 day cycle (75 mm). However, the **intention** of the 7 day cycle was to increase the frequency of filling and draining the Drainable Porosity (DP) store over the active soil profile.

Figure 2 shows the variation in water table depth over the irrigation season. The hydrologically effective soil depth for the 7 day cycle reduces from 1,200 mm to 300 mm as a semi permanent perched water table develops above the agricultural drains. A similar but more attenuated response occurs for the 14 day cycle with hydrologically effective soil depth reducing from 1,400 mm to 800 mm. Because the pumping phase is longer in the 14 day cycle (10 days) there is more opportunity for the water table to fall below the soil surface. The net result is that the 7 day cycle fills DP more frequently, but the size of DP is reduced because of the reduced variation in water table depth.

A summary of the hydraulic performance over the 1999 summer cropping season is listed in Table 1.

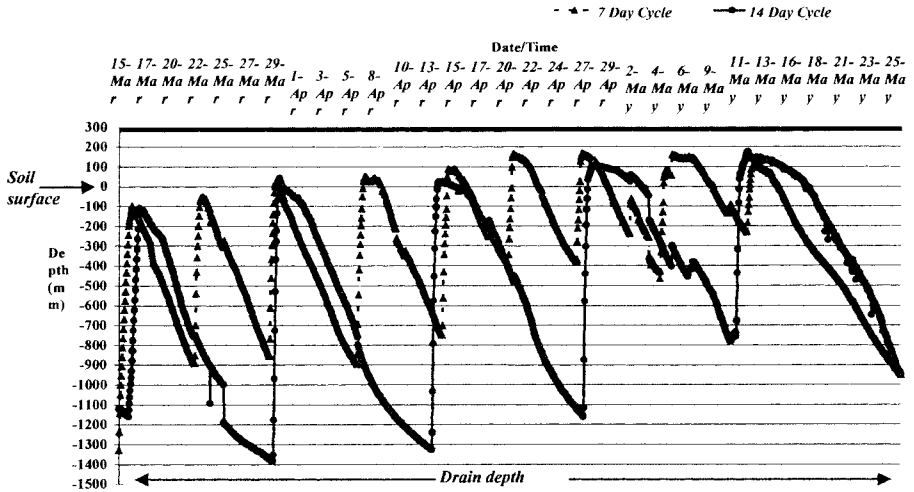


Figure 2 Water levels below the soil surface in the two FILTER bays over the summer season March–May 1999

Table 1 Summary of the Water Balance components of the two FILTER bays for the 1999 summer season

Bay	Period Days	Change in W/T (mm)	Specific Yield (%)	Water ON (mm)	Rain (mm)	Water OFF (mm)	PAN (mm)	ET (mm)	DD (mm)	LF (%)
Weekly 1	7.0	791.7	1.0	70.5	0.0	7.6	37.2	37.2	25.7	11
Weekly 2	7.0	840.7	2.1	63.7	1.6	18.0	32.2	32.2	15.1	28
Weekly 3	8.0	890.6	2.7	61.5	4.4	23.9	40.2	40.2	1.7	39
Weekly 4	7.5	723.3	1.8	71.6	0.4	13.3	40.3	40.3	18.4	19
Weekly 5	6.0	396.1	4.6	67.8	12.1	18.0	33.8	33.8	28.1	27
Weekly 6	6.5	374.1	4.4	72.9	0.0	16.4	22.4	22.4	34.2	22
Weekly 7	6.5	366.8	6.0	78.2	14.8	22.0	36.6	36.6	34.4	28
Weekly 8	9.0	215.7	7.7	75.1	16.8	16.7	51.0	51.0	24.2	22
Weekly 9	7.3	378.5	4.4	33.6	7.3	16.8	16.1	16.1	8.0	50
Totals	64.8			594.8	57.4	152.7	309.8	309.8	189.7	26
Averages/Day			3.9	9.2	0.9	2.4	4.8	4.8	2.9	
Fortnightly 1	14.0	928.2	1.2	51.6	1.6	11.5	64.8	64.8	0.0	22
Fortnightly 2	14.5	1285.4	2.2	113.9	4.8	28.6	67.6	67.6	22.5	25
Fortnightly 3	14.0	1193.3	3.6	110.8	12.1	43.5	53.5	53.5	25.9	39
Fortnightly 4	14.0	769.3	5.4	146.9	24.6	41.7	60.4	60.4	69.5	28
Fortnightly 5	15.3	934.0	4.1	160.3	16.9	38.3	61.4	61.4	77.5	24
Totals	71.8			583.6	60.0	163.5	307.7	307.7	194.5	28
Averages/Day			4.1	8.1	0.8	2.3	4.3	4.3	2.7	

W/T = Water Table. DD = Deep Drainage. LF = Leaching Fraction. Pan = Class A pan evaporation. ET = Evapotranspiration.

Table 1 also lists the Specific Yield (S_Y) for both FILTER bays on an event and seasonal basis. S_Y is the ratio of drainage water pumped from the sumps (in mm equivalent depth) and the change in water table depth (mm). Over a seasonal basis (9 weeks) the average S_Y is 4% volumetric with little difference between the two FILTER bays. In comparison the S_Y calculated for the deep ripped Alfisol examined by Jayawardane *et al.* (1997) was approximately 7% v/v, and this was maintained over at least four cropping cycles.

An important feature of FILTER is that the effluent applied is substantially larger than that for a conventionally irrigated cropping system. Table 1 shows that the applied effluent (580–600 mm) is substantially greater than the 250mm irrigation demand. A substantial

amount of the surplus irrigation has been rerouted as deep drainage (DD) below the agricultural drain depth. Calculated DD (mm) values are listed in Table 1 and suggests DD losses are of the order of 190mm per season, equivalent to *c* 3 mm/day. Unacceptable nitrate-N contamination of the deep groundwater is unlikely as the nitrate levels in the renovated water collected in the sumps is usually ≤ 5 mg/L $\text{NO}_3\text{-N}$ (Figure 3).

Nitrogen response

The total nitrogen concentration applied in the effluent and removed in the discharge water is shown in Figure 3, and apart from some early peaks associated with pre irrigation drainage events (i.e. before 15 March 1999) caused by rainfall, the drainage water concentration is usually less than 5 mg/L TN for both the 7 and 14 day cycle bays. The 7 day cycle has a consistently lower N concentration than the 14 day cycle presumably because increased soil water logging conditions promoted denitrification (Keeney 1981). The lagoon effluent was dominated by $\text{NO}_3\text{-N}$ (70% of TN) which predisposes the soil-water system to N loss. Taken overall, the N removal was 90% and 85% for the 7 day and 14 day FILTER bays respectively, noting however that N lost by deep percolation (Table 1) is implicitly included in this loss estimate.

Mass balance results from Jayawardane *et al.* (1997) also reported N losses of the order of 85% over a summer effluent application season with an N loading of *c* 100 kg/ha. In addition, approximately 360 kg/ha of pre-existing soil $\text{NO}_3\text{-N}$ was removed by a combination of denitrification and crop uptake (about 90 kg/ha N) illustrating the extremely efficient denitrification potential of the FILTER system.

Nonetheless the N “challenge” to the FILTER system at Gatton has *not* been particularly taxing as N concentrations during irrigation were of the order of 10 mg/L TN (Figure 3) with a total seasonal N loading rate of *c* 50 kg/ha. Trickling filter plants in Queensland usually have values of 20 to 30 mg/L TN (Gardner *et al.* 1998).

Phosphorus response

The time trends in TP in both the effluent applied and in the drainage waters are shown in Figure 4 and P has been reduced to concentrations ≤ 1 mg/L compared with input concentrations of *c* 5–6 mg/L TP. Using mass balance calculations (P on vs P off), the amount of P

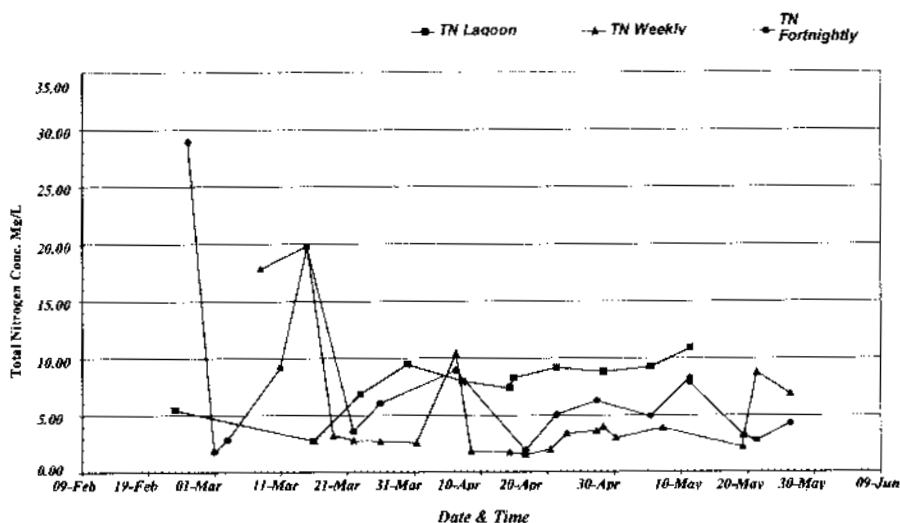


Figure 3 Total Nitrogen Concentrations in the effluent lagoon and FILTER bays leachate over the summer season March–May 1999

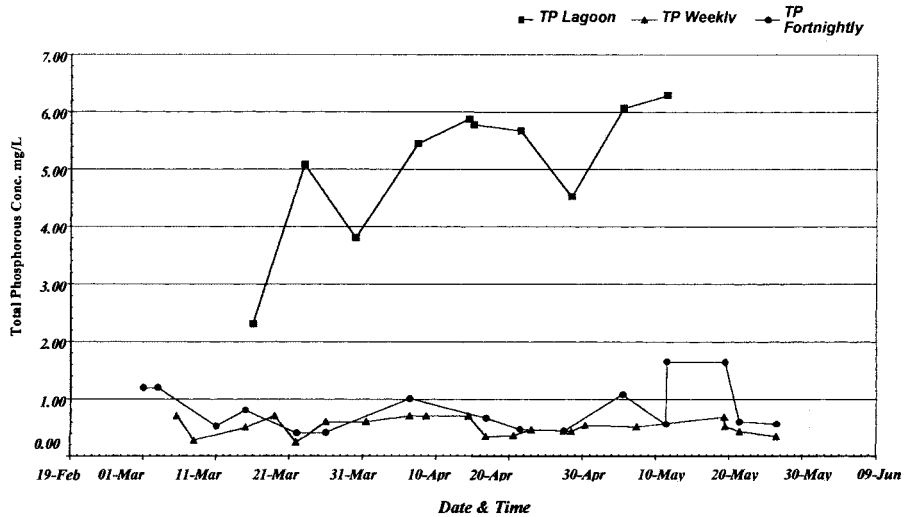


Figure 4 Total Phosphorus Concentrations in the effluent lagoon and FILTER bays leachate over the summer season March–May 1999

removed is in excess of 95% of the P applied (about 30 kg/ha) and this removal efficiency is similar to the results reported by Jayawardane *et al.* (1997).

Unlike N, the major removal mechanism for P is by soil adsorption reactions involving processes well described in the agricultural literature (e.g. Syers and Iskander 1981). Many Australian soils have high P immobilising ability (Barrow 1980). For the Vertisol at Gatton, the potential P fixing ability of 1.5m of soil profile irrigated with effluent containing 5 mg/L orthophosphate-P is 1800 kg/ha, giving a conservative sustainable soil life for FILTER of about 20 years.

Other pollutants

Other pollutants we used to gauge the effectiveness of the FILTER system included BOD and faecal coliforms. The responses we have measured have been indifferent or ambiguous. For example, after the first few effluent irrigations, the BOD of the lagoon effluent reduced to ≤ 10 mg/L and remained essentially unchanged both in time and by the soil filtering process.

Faecal coliform concentrations in the lagoon effluent were predominantly in the range $\geq 5,000$ cfu/100 ml for most of the season, with little reduction occurring in the 7 day bay, and a rising trend line (from < 10 to $\geq 2,000$ cfu/100 ml) in the 14 day bay. We are uncertain as to the reasons, but suggest that a combination of short circuiting of ponded effluent through the backfilled drainage trenches (Figure 1), insufficient retention time in the soil matrix, and leaching of animal sources of faecal coliforms may be responsible.

Salinity

Figure 5 shows the variation in EC for the lagoon effluent and the drainage water. Apart from the peaks in EC occurring early in the season (presumably from leaching pre existing soil salts) the 7 day and 14 day bays have relatively constant salinities of the order of 1.5 dS/m and 2.5 dS/m respectively, compared with a lagoon effluent EC of 0.55 dS/m.

Using steady state mass balance principles (i.e. $EC_{OFF} = EC_{ON}/LF$) and the Leaching Fraction (LF) data of Table 1, the expected increase in drainage water salinity is about 4 fold to about 2.2 dS/m (i.e. $0.55 \text{ dS/m} \times 0.25$). Whilst this predicted increase occurred in the

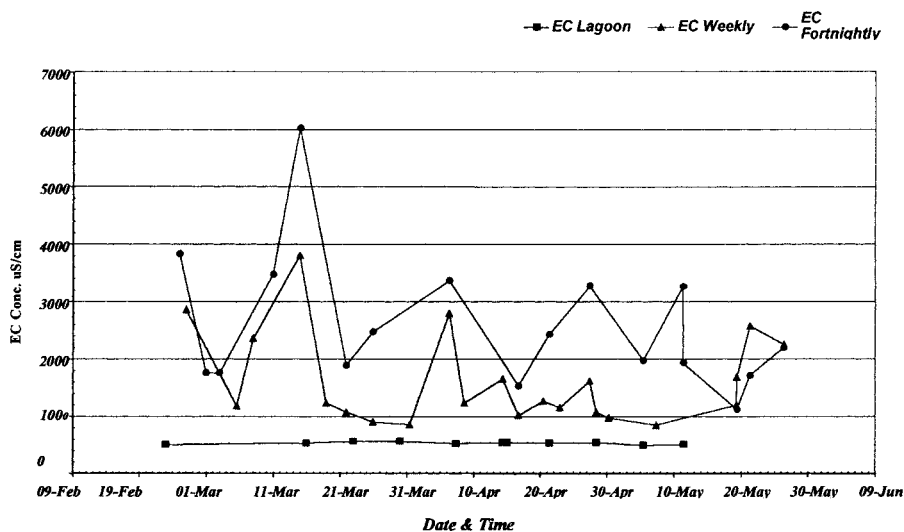


Figure 5 Electrical Conductivity of the lagoon effluent and FILTER bays leachate over the summer season March–May 1999

14 day bay (*c* 2.5 dS/m) the 7 day bay's salinity only increased 2 fold (to *c* 1.4 dS/m) suggesting another source of solute leaching. The deep percolation figures in Table 1 (about 190 mm) could make a substantial contribution to leaching of applied solutes, but it is unclear why such different salinity behaviour would occur between the 7 and 14 day bays.

Nonetheless, the salinity of the drainage water even at 2.5 dS/m is acceptable for irrigating a wide range of crops (Ayres and Westcot 1985). In comparison, the drainage water produced in the Griffith FILTER studies was of the order of 12 dS/m compared with an effluent salinity of *c* 0.7 dS/m (Jayawardane *et al.* 1997). This large salinity increase was primarily due to the leaching of a pre-existing high soil salt store.

Conclusions

We have tested the FILTER system in a biophysical setting substantially different from the soil and site conditions under which it was developed. After one cropping cycle it is clear that the hydraulic loading of effluent can be substantially larger than the irrigation demand of conventional irrigation systems. However this high loading occurs in part because of substantial percolation losses below the agricultural drain depth. Percolation losses were not an issue in the original FILTER study (at Griffith) because of a shallow regional water table. We found no particular advantage in reducing the 14 day cycle to 7 days, because a semi permanent perched water table reduced the potential size of the Drainable Porosity.

The N and P load reductions we found ($\geq 85\%$) are very similar to the Griffith FILTER results. This was expected for the soil dominated P removal process, but the high relative NO_3 composition of the Gatton effluent may have predisposed the system to high denitrification losses. Moreover the concentration of TN in the effluent (8–9 mg/L) and the N load we applied (50 kg/ha N) was not particularly challenging to the FILTER system. We intend to explore this idea by increasing the N concentration in the applied effluent to values more representative of trickling filter effluents in Queensland (about 25–30 mg/L TN).

The salinity of the drainage water at Gatton is suitable for irrigating a wide range of agricultural crops. This will not always be the case if saline soils are used for FILTER bays. Reduction of other pollutants we measured have been ambiguous or disappointing either because of their low concentration in the lagoon effluent (e.g. BOD) or because of short

circuiting pathways and external non effluent sources (e.g. faecal coliforms). We intend to clarify some of these issues by tracking the change in concentration in the bacteriophage MS-2 after spiking the effluent (Havealaar *et al.* 1993).

Nonetheless we believe that FILTER is one of the most innovative land-based effluent treatment/reuse systems to be developed over the last decade. It gives relatively land rich rural local authorities the opportunity to produce lost cost tertiary treated effluent using a relatively simple level of engineering technology.

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