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Subsurface dripline tubing — an experimental design for assessing the effectiveness of using dripline to apply treated wastewater for turf irrigation in Western Australia

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Abstract

Using sub-surface dripline has several advantages over sprinklers, when irrigating with treated wastewater. However, sprinklers are still preferred for landscape irrigation in Western Australia (WA). A trial funded by the Water Corporation is currently being conducted in the Town of Northam. The trial will test the effectiveness of sub-surface dripline for use with reclaimed water in municipal parks and gardens. This paper describes the methodology and indicates expected outcomes. The literature reviewed suggests that although subsurface dripline has limitations, it should effectively irrigate turf if care is taken to install and manage a system properly. Like any method of effluent irrigation, consideration must be given to the impacts of nutrients, salts, pathogens, and other potentially detrimental species in the water. Local councils in WA, and elsewhere, may gain information from the results, which will be useful when evaluating the option of using dripline for wastewater irrigation.

Keywords: Sub-surface dripline; Turf; Irrigation; Treated wastewater

1. Introduction — water reuse in Western Australia

Australia's water reuse has changed rapidly since the 1990's. Generally, the proportion of water reused has increased [1]. In Western Australia, water reuse increased from 0% in 1999 to 10% in the 2002–2003 period [2]. This increase has probably been encouraged by the approximately 40% reduction in run-off into dams south-west WA has experienced over the last three

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decades. Rainfall has also reduced by about 15%, and recent predictions indicate these trends will continue in the future [3].

It seems likely that the State Water Strategy objective to beneficially reuse 20% of wastewater effluent by 2012 will be met [3]. The biggest contribution towards this target now comes from country towns, which reuse about 40% of all their municipal wastewater, or 5.5% of the state's wastewater. The high reuse rate in country towns is attributed to the limited supply of water, and the high cost of alternatives [3]. Sprinkler irrigation is currently the most common method of applying treated wastewater to municipal areas in WA.

The Perth metropolitan area has a lower reuse rate than rural areas. Most of Perth's reused treated wastewater is used by industry. [3] Many opportunities for reuse in Perth are yet to be utilized. Although the 150 gigalitres a year of water required for horticulture, parks and gardens in Perth could be supplemented by treated wastewater, it is not [4]!

100 gigalitres per year of Perth's wastewater is disposed of through ocean outfalls. It is possible that the public's increasing environmental awareness could encourage Perth, and other coastal towns, to find other disposal practices in the future, including reuse. This is consistent with the town Busselton's 1998 rejection of a proposal to discharge effluent into the ocean because it was unpopular with the public [5]. Inland areas have never been able easily to dispose of effluent through ocean outfalls. Necessity requires them to use other methods such as land-based irrigation, evaporative ponds, or groundwater recharge.

Local councils that use land-based irrigation of wastewater effluent must overcome several hurdles including: complying with health regulations, garnering public support for the activity, ensuring no damage is done to the environment, and choosing an appropriate way to apply the effluent. In this situation, sub-surface dripline has many benefits which other types of irrigation, such as sprinklers, do not [6]. Northam, like 70 other West Australian towns, has used sprinklers to irrigate parks, gardens and sporting facilities with treated wastewater for some years [7]. The trial currently running in Northam, an inland town, is described below and will assess the effectiveness of sub-surface dripline for irrigation of turf with treated wastewater.

2. Literature survey

Some issues that arise when treated effluent water is used for irrigation of municipal areas include: public health, technology availability and reliability, social acceptance, monitoring systems and environmental sustainability (e.g. sodicity, heavy metals build-up) [1]. These issues, together with technology availability, will be considered in the following literature review. The experiment described in Section 4 will further investigate technology availability and reliability, with a specific focus on sub-surface dripline.

2.1. Dripline and sprinkler irrigation

A comparison of sub-surface dripline with sprinklers (Table 1) shows that dripline has two important advantages (amongst others) over sprinklers: higher water-use efficiency and reduced health risks [6]. Dripline is considered "efficient" because it loses almost no water to evaporation, run-off or overspray.

A comparison of sprinklers with sub-surface dripline to apply treated effluent water on Bermuda grass [8], indicated that there were no significant differences between the two irrigation systems in Bermuda grass health. However, root distribution and activity appeared to be more restricted when irrigated by (surface) dripline than sprinklers in a trial using tomato and peanut plants [9.] Driptape (low flow, low pressure) trialled in California was also considered suitable for use with activated sludge secondary effluent [10]. Therefore using dripline, rather than sprinklers,

Table 1
Benefits and limitations of sub-surface dripline irrigation compared to sprinkler irrigation. Adapted from Byrne [6]

Benefits	Limitations.
Higher water efficiency	Drippers can clog from iron precipitates
Reduced weeds	Root intrusion into drippers
Reduced plant disease	Doesn't protect from frost like sprinklers can
Flexible watering times	Leaks/blockages more difficult to see.
More saline water tolerated by plants (less leaf burn)	Unsuitable for seed germination
Flexible installation in odd/narrow irrigation areas.	Installation is not a robust process. Correct installation and maintenance are essential
Runs on low pressure- gravity feeding can be possible	
Reduced vandalism costs.	*Higher level of filtration required than sprinklers (to prevent drippers clogging).
*Reduced public health risk	

*Characteristics specific to effluent irrigation

for irrigation with treated wastewater should not compromise turf health.

2.2. The effectiveness of dripline irrigation

Performance of dripline with effluent is mainly limited by dripper (emitter) clogging e.g. with organics or salts [11]. The system uniformity degrades, which in turn lowers the irrigation efficiency. Appropriate filtration of the water supply can help minimise blockages. Dripper flow rates also affect the likelihood of clogging. Drippers at several flow rates were trialled with lagoon wastewater and the experimenters found that although the larger flow drippers (≥1.5 L/h/emitter) experienced little decrease from the original flow over time, while the smaller dripper sizes (0.91 L/h/emitter or less) "may be risky" [12]. The latter are generally not recommended by dripline manufacturers for effluent use.

Taking care not to allow soil particles to enter a system when under construction or repair is necessary to prolong dripline system life [13]. Root intrusion is another cause of dripper blockage. It can occur when plants are water stressed. In the trial with Bermuda grass [8], root intrusion was experienced in plots with sandier soils i.e. plots with lower soil water holding capacity. A thorough knowledge of site soil types when designing a system is required for an effective dripline system. In addition to appropriate set up, regular maintenance must be undertaken (e.g. acid/ chlorine injection) to prevent dripper clogging. If these measures are taken, evidence suggests that dripline should be as effective as any other kind of effluent irrigation.

2.3. Social acceptance of water reuse

Community perception of public health risk largely dictates the social acceptability of water reuse [1]. Low-human-contact uses of treated effluent are generally accepted, although this acceptance decreases with higher contact uses (e.g. drinking), which are seen as being riskier. Water reuse for lawn irrigation was supported by 99% of respondents in a South Australian 2003 study [14]. In a WA study by the Water Corporation, people rated the idea of water reuse "very positively" [15]. In light of these trends, a council wishing to reuse water by irrigating turf would probably have good public support.

2.4. Public health risk

Dillon [1] notes that in Australia, although acceptance of reuse is high, "a failure [e.g. epidemic breakout] at even one site may do much to damage implementation of wastewater use nationally…development opportunities would be forgone Australia-wide if public opinion turned against [water] recycling."

Health can be compromised by public exposure to sprinkler irrigated effluent by wind overspray, ponding, and run-off, or by groundwater contamination resulting from over-watering. Therefore it is important to minimise the occurrence of these events, and sub-surface dripline eliminates over-spray.

Microbiological survival in contaminated groundwater is not well understood, but there is some indication of extended pathogen survival [16]. Thus, irrigation scheduling should aim to avoid over-watering, reducing the amount of effluent leaching into the groundwater.

Evidence suggests that pathogenic viruses from effluent can survive for long periods of time in soils [17]. However, it appears that the passage of effluent through the soil considerably reduces the number of micro-organisms. This has been indicated in studies with above ground and sub-surface dripline [18,19], and when both high and low quality effluents were used with drip irrigation [20]. Although the risk to public health is probably greater when effluent is used for irrigation than when scheme water is, the amount of pathogens present in the effluent is reduced by soil filtration.

Irrigation of treated effluent must comply with AS/NZS 1547 [21]. Some requirements which aim to protect public health are: the application rate must not exceed soil absorption capacity (4.2A10.3.1); no run-off or seepage of effluent is allowed beyond the designated irrigation area (4.2A10.4.2d); and ensuring effluent does not come into contact with people or domestic animals (4.2A10.5d). Anecdotal evidence suggests that many or most towns using sprinklers to apply treated effluent are in breach of legislative requirements, particularly those mentioned above. There is documented evidence of breaches in Northam [22]. Other irrigation methods could have characteristics which allow the legislation to be more easily complied with. These should be investigated.

2.5. Environmental considerations

The environmental factors most likely to limit effluent reuse are: excessive nitrate leaching, poor salt management, and increases in soil sodicity [23][1]. It is recommended that the management practices of minimum tillage, addition of gypsum (calcium sulphate), and maintaining high soil organic matter turnover are used [24,25]. A benefit of the effluent nutrient loading is a reduction to the amount of chemical fertilizer required by the crop [3].

Nitrate migration is thought to be less problematic than phosphorus migration, because nitrate is readily absorbed by plants, and can be reduced to nitrogen gas [26]. However, experimental evidence suggests that in sandy soils, nitrogen is lost by leaching, rather than denitrification [27]. This is due to the soil's aeration, which doesn't encourage denitrification. Although N levels in soil might be expected to increase when effluent is applied, this has not been supported by all field trials [8].

Phosphorus may also build up when effluent is applied. Excess P is stored in the soil or flushed down to groundwater. The rate of P flushed depends on the soil's PRI (Phosphorus Retention Index). Although the PRI of a soil is dependant on many factors, a simplistic summary is that: more clayey, acidic, soils have higher PRIs, while sand has a PRI close to zero. An increased iron or aluminium content correlates with an increased PRI [26]. The loamy soil at the Northam trial site will therefore hold more P than some other South WA sandy soils. Ideally, the amount of P applied by the effluent should balance the plant P uptake.

The salt from effluent can build up in soil if not flushed past the root zone. This could be a problem in arid regions where treated effluent is

[1] Although soil microfauna are also important to the health of a soil, some evidence indicates that they are probably not adversely affected by irrigation with effluent, provided there is minimal heavy metal contamination. Species compositions may change, however. [29].

used for irrigation. However, south-west WA's heavy winter rains help prevent salinity in these situations. In a comparative study of sprinklers and dripline, there was evidence of salt accumulation near the ground surface in the dripline plots, but turf appeared unaffected [28].

High sodicity is a related problem. Sodicity is a measure of the preponderance of exchangeable sodium ions compared to other cations [30]. Soils irrigated with effluent commonly experience increases in Exchangeable Sodium Percentage (ESP). For example, in a Wagga Wagga trial, ESP increased 23% after 5 seasons of effluent irrigation [31]. Increased ESP causes an increased tendency for soil dispersion, a decrease in the volume of large soil pores, increased soil water retention, and a decrease in hydraulic conductivity. However, hydraulic conductivity can be maintained by minimising soil disturbance. Balks [31] concluded that although increased sodicity is unlikely to affect effluent irrigation use, it might affect the suitability of the land for alternate uses that involve physical disturbance of the soil. Jnad et al. [32] found that when wastewater was irrigated with sub-surface dripline, the soil slightly below the drip emitter was most affected by decreases in hydraulic conductivity.

Hydraulic conductivity can also decrease when soil pores become blocked with microbial biomass. Although a field experiment [33] showed no significant evidence of reduced hydraulic conductivity of sandy soils irrigated with effluent, the laboratory trial demonstrated that effluent with a high C:N ratio can result in decreases in soil hydraulic conductivity. In order to avoid damage to soils, monitoring changes in soil hydraulic conductivity seems advisable, so that land management practices can be altered if required.

3. Research questions

The project will evaluate the effectiveness of subsurface dripline irrigation for use with effluent water. An experimental trial of four products has been set up in the Town of Northam. A comparison between the products is not the aim of the project *per se*, rather, the use of several products aims to eliminate the bias created by product-to-product differences. Generic dripline, instead of a particular product, will be considered, thus increasing the applicability of the results.

The following questions will be examined;

1. What are the criteria that determine the dripline product's suitability for use with reclaimed water in municipal irrigation systems? (See sections 2.1, 2.2, 2.5)

2. Is the operational performance of currently available dripline products satisfactory for subsurface irrigation of treated wastewater on turf in municipal parks?

3. If the dripline is considered suitable for use in municipal irrigation systems, what are the operational and maintenance requirements for maximum beneficial use?

4. Experimental design and methods

4.1. Irrigation trial site

Several areas were available in Northam for the trial. The sites were evaluated by assessing uniformity of sunlight, slope, and soil type, how representative the site was of a municipal turf area and ease of setting up the experiment. The chosen site is a disused tennis court, with a skate park in the north-east corner. The grassed site is flat, in full sun, and is near a pump which supplies treated wastewater. Although it is across the road from Northam high school, the grassed area appears to experience little public use. A strip of turf (approximately 10 m) around the skate area is currently sprinkler irrigated from the pump. The soil texture is sandy loam.

4.2. Product selection

The products were selected for their availability in Western Australia, and their suitability for use with wastewater. A product will be trialled from each of the following companies: Netafim Australia, Kiter Pty Ltd., Plastro Asia Pacific, and Triangle Filtration and Irrigation. They have been installed to the manufacturer's specifications which are detailed in Table 2.

4.3. Experimental design and methods.

The trial will run for one year. Twelve plots (5 m x 5 m) were marked out at the site, leaving a thirty meter buffer between the skate area and the trial to prevent wind-spray from the sprinklers from confounding results (Fig. 1). A randomised block design was used to allocate three replicate plots to each of the four products. These three plots are joined on a sub-main. Each of the four sub-mains is connected to a solenoid, which is wired to the controller (an electronic timer). The sub-mains then join the mainline. A non-watered area will be used as a control.

All plots will receive the same amount of water. The irrigation scheduling (Table 2) has been calculated as detailed in Appendix 1. The scheduling will be adjusted seasonally, and also (if required) to compensate for over-/under-watering errors due to inaccurate estimates in the scheduling calculations.

Several factors have been chosen as indicators of the effectiveness of the dripline (Table 3). These are: flow rate to plots, leachate volume and nutrient content, soil moisture, turf condition, and sediments in the dripline. Meteorological data will be monitored.

A lysimeter is a device which measures the volume of leachate per unit area percolating past the root zone (Fig. 2). Captured leachate flows from the lysimeter into a holding container, where it can be pumped out through an inspection tube later. The initial (first month) amount of leachate will act as a scheduling tool. If an excess volume is found, the scheduling will be adjusted.

5. Preliminary and expected results

During the installation it was noted that soil type appeared to vary across the site more than originally estimated. Further testing of soil texture and permeability is needed. Significant non-uniformity across the site will require adjustments to the application rate. However, it should not affect run-off rate because the site is flat.

It is expected that the flow rate to each plot will remain constant. A change in flow can indicate various problems with the system, such as blocked drippers. Increases in flow will occur to plots when the dripline leaks or breaks, but once repaired flow is expected to return to the original rate. Broken dripline can be indicated by wet patches of surface soil.

Table 2
Product specifications (depth, line spacing, dripper spacing, flow rate) and irrigation scheduling

Supplier	Netafim	Kiter	Plastro	Triangle
Product	Bioline Purple 17 mm diameter	Safety Flow 16 mm	Hydro P.C. N.D. Purple 16 mm	GeoflowTM WasteflowTM 16 mm tube
Dripper flow, L/h	1.6	2.6	1.6	2.4
Dripper spacing, m	0.4	0.4	0.3	0.6
Line spacing, m	0.4	0.5	0.45	0.4
Depth, m	0.1	0.1	0.1	0.1
Flow, L/h/m^2	10	13	11.85	10
Net water requirement, L/m^2	15	15	15	15
Irrigation interval, d	3	3	3	3
Duration	1 h 30 min	1 h 9 min	1 h 16 min	1 h 30 min
Plot numbers	1, 3, 12	6, 7, 11	4, 9, 10	2, 5, 8

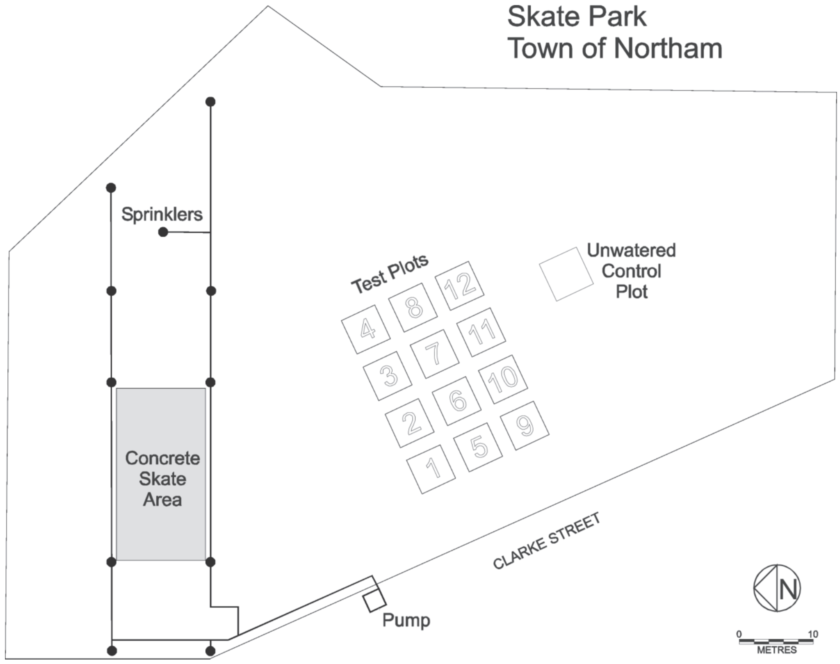

Fig. 1. Layout of plots, existing sprinkler system, and mainline. All ground is turfed except for the concrete skate area. Sub-mains are not shown.

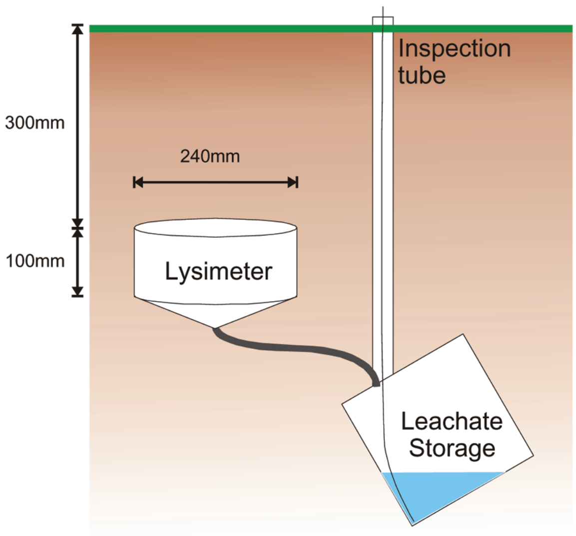

Fig. 2. An installed lysimeter. Water travels through the root zone below the turf, into the lysimeter, and is then stored in a collection chamber.

Another problem that wet patches can indicate is over-watering. If over-watering occurs, large amounts of leachate should be found from the lysimeters. If one assumes that the irrigation scheduling is appropriate, then there should be a limited amount of leachate from the lysimeters. The data from the initial monitoring supports this hypothesis. So far, large volumes (>5 mL) of leachate have only been found in lysimeters from five plots, all of which were amongst the plots inadvertently watered twice the application rate. This obvious over-watering only occurred in half the plots (i.e. six), and resulted from a problem with the controller programming. No leachate, or very little (<5 mL) was obtained from the lysimeters of plots receiving the desired amount of water.

The nutrient loading of the leachate is expected to be lower after filtering through turf [35]. The

Table 3
Monitoring of trial, type and frequency of data collected

Measurement	Measured by	Frequency	Notes
Plot flow rate (L watering h^{-1})	Flow meter on each plot	Twice monthly	Changes in flow rate can indicate system malfunctions
Leachate volume (mm m^{-2})	Lysimeter 300 m beneath each plot	Monthly	Volume compared with non-watered control
Leachate nutrient loading (pH, EC, total nitrogen, total phosphorus, organic N, nitrate/nitrite, reactive P, inorganic P)	Lysimeter 300 m beneath each plot. Analysis by Murdoch lab	Monthly	Compared with loading of holding dam
Pathogens (E. coli, thermotolerant coliforms [cfu 100 mL^{-1}])	Lysimeter 300 m beneath each plot. Analysis by Water Corporation	Monthly	Compared with pathogen content of holding dam and control
Soil moisture content (% soil moisture every 100–500 mm)	Enviroscan Diviner	Twice monthly	Enviroscan use provided by John Forrest
Dripline sediments (photo record + sediment dry weight)	Cutting open 1 sacrificial line per plot	6 monthly	Clogging could be from algal growth, root intrusion or salt deposits
Turf condition (photo record)	Digital camera	Twice monthly	
Meteorological data (temperature, evaporation, solar radiation, rainfall)	Bureau of Meterology Northam Station, Northam.	Daily	
Other observations (mowing, water ponding, vandalism, etc.)	Log by Northam parks and gardens, field observations when sampling	Ongoing	

literature reviews suggested that the pathogen count in the leachate will also be lower than the treated wastewater. No nutrient data from this experiment is available yet.

The soil moisture levels are expected to be highest at 100 mm, corresponding to the dripline depth, becoming dryer above and below that level. This would indicate that the water has been applied to and remains in the root zone. If the results demonstrate that the turf receives adequate water, without being over-watered, then the dripline could be considered “effective” in that regard.

6. Conclusion

The data obtained by the monitoring process should give insight into the research questions: What determines the suitability of dripline for irrigation? Are the available products suitable? What are the operation and maintenance requirements? This paper is about an experiment in progress. The experiment has been designed and set up, but conclusive results are not available yet. However, we expect that the results will support the literature reviewed.

If the literature is used to evaluate the use of subsurface dripline for irrigating turf with treated wastewater, then dripline appears be an effective irrigation method. However, sub-surface dripline has limitations which must be understood in order to gain maximum benefit from its use. (The limitations mainly arise from the need to keep drippers from clogging, and to maintain an irrigation system which isn’t readily seen once installed).

In addition to the limitations arising from the characteristics of sub-surface dripline, consideration needs to be given to the limitations of irrigating with treated wastewater (rather than potable water). Like other technologies, effectiveness can depend as much on appropriate usage as on design characteristics.

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References

[1] P. Dillon, Water reuse in Australia: current status, projections and research, Proc. Water Recycling in Australia 2000, P. Dillon, ed., Adelaide, 2000, pp. 99–104.
[2] Water Corporation, Annual Report 2003. Flowing Forward. Water Corporation, Western Australia, 2003.
[3] Government of Western Australia, Securing our Water Future: A State Water Strategy for Western Australia. State Government of Western Australia. Western Australia, 2003.
[4] Government of Western Australia, Securing our Water Future: A State Water Strategy for Western Australia One Year Progress Report. State Government of Western Australia, Western Australia, 2004.
[5] Water Corporation, Busselton Wastewater Treatment and Disposal. Water Corporation, Perth, 1998.
[6] J. Byrne, A Dripping Good Time. The Organic Gardener Summer 2003/2004, 2003, pp. 33–38.
[7] J.C. Radcliffe, Water Recycling in Australia. Australian Academy of Technological Sciences and Engineering, 2004.
[8] I. Jnad, B. Lesikar, A. Kenimer and G. Sabbagh, Subsurface drip dispersal of residential effluent: I. Soil chemical characteristics. Trans. ASAE, 44(5) (2000) 1149–1157.
[9] J. Benasher and M. Silberbush, Root distribution under trickle irrigation —factors affecting distribution and comparison among methods of determination. J. Plant Nutrition, 15(6–7) (1992) 783–794.
[10] D. J. Hills and M.J. Brenes, Microirrigation of wastewater effluent using drip tape. Appl. Eng. Agriculture, 17(3) (2001) 303–308.
[11] A. Capra and B. Scicolone, Emitter and filter tests for wastewater reuse by drip irrigation. Agric. Water Management, 68(2) (2004) 135–149.
[12] C.R. Camp, E.J. Sadler and W.J. Busscher, A comparison of uniformity measures for drip irrigation systems. Trans. ASAE, 40(4) (1997) 1013–1020.
[13] T.P. Trooien, F.R. Lamm, L.R. Stone, M. Alam, D.H. Rogers, G.A. Clark and A.J. Schlegel, Subsurface drip irrigation using livestock wastewater: Dripline flow rates. Appl. Eng. Agriculture, 16(5) (2000) 505–508.
[14] J. Mckay and A. Hurlimann, Attitudes to reclaimed water use: Part 1. Age. Water, August (2003) 45–49.
[15] Water Corporation of Western Australia. Community Attitudes and Public Perceptions. Water Recycling Workshop, Perth, Western Australia, June, 2003.
[16] S. Pedley and G. Howard, The public health implications of microbiological contamination of groundwater. Quart. J. Eng. Geology, 30 (1997) 179–188.
[17] R. Blanc and A. Nasser, Effect of effluent quality and temperature on the persistence of viruses in soil. Water Sci. Technol., 33(10–11) (1996) 237–242.
[18] C. Campos, G. Oron, M. Salgot, L. Gillerman and G. Casals, Behaviour of the fecal pollution indicators in a soil irrigated with treated wastewater under on surface and subsurface drip irrigation. Water Sci. Technol., 42(1–2) (2000) 75–79.
[19] C. Enriquez, A. Alum, E.M. Suarez-Rey, C.Y. Choi, G. Oron and C.P. Gerba, Bacteriophages MS2 and PRD1 in turfgrass by subsurface drip irrigation. J. Environ. Eng., ASCE, 129(9) (2003) 852–857.
[20] C. Campos, G. Oron, M. Salgot, L. Gillerman and G. Casals, Attenuation of microorganisms in the soil during drip irrigation with waste stabilization pond effluent. Water Sci. Technol., 42(10–11) (2000) 387–392.
[21] Standards Australia/Standards New Zealand. AS/NZS 1547:2000.Australian/New Zealand Standard On-site domestic-wastewater treatment. Standards Australia International Ltd, 2000.

[22] M. Anda, Effectiveness of Subsurface Dripline Tubing for Irrigation of Reclaimed Water in Public Open Space Turf in Northam. Field report to the Water Corporation, March 2004.
[23] W.J. Bond, Effluent irrigation; an environmental challenge for soil science. Australian J. Soil Res., 36(4) (1998) 543–555.
[24] W. Meyer, The effect of agriculture on soil water bodies. In: Fixing the Foundations. The Role of Soil Science in solving Australia's Crisis in Land and Water Management. Australian Academy of Science, Canberra, 1999.
[25] P. Donlon and A. Surapaneni, Managing effluent irrigation: the sodification threat. Water, 27(5) (2000) 45–48.
[26] R.G. Gerritse, Movement of Nutrients from Onsite Wastewater Systems in Soils. Department of Health, Water and Rivers Commission, DEP, and DPI: Perth, WA, 2002, pp. 1–34.
[27] W. Smith and W.J. Bond, Losses of nitrogen from an effluent-irrigated plantation. Australian J. Soil Research, 37(2) (1999) 371.
[28] E. Suarez-Rey, C.Y. Choi, P.M. Waller and D.M. Kopec, Comparison of subsurface drip irrigation and sprinkler irrigation for Bermuda grass turf in Arizona. Trans. ASAE, 43(3) (2000) 631–640.
[29] E. Gupta, S. Rodgers and R. Naidu, Effects of secondary treated sewage effluent application on the populations of microfauna in a hardwood plantation soil; Geoderma, Bolivar HIAT trial. EGeoderma, 84(1–3) (1998) 249–263.
[30] R. van de Graaff and R.A. Patterson, Explaining the mysteries of salinity, sodicity, SAR and ESP in on-site practice. Proc. On-site '01 Conference: Advancing On-site Wastewater Systems, R.A. Patterson and M.J. Jones, eds., Lanfax Laboratories, Armidale, 2001.
[31] M. Balks and W.C. Smith, Effects of sodium accumulation on soil physical properties under an effluent-irrigated plantation. 14th New Zealand Land Treatment Collective Meeting, P.J. Polglase and W.M. Tunningley, eds., New Zealand, 1996, pp. 195–200.
[32] I. Jnad, B. Lesikar, A. Kenimer and G. Sabbagh, Subsurface drip dispersal of residential effluent: II. Soil hydraulic characteristics. Trans. ASAE, 44(5) (2001) 1159–1165.
[33] G.N. Magesan, J.C. Williamson, G.P. Sparling, L.A. Schipper and A.R. Lloyd-Jones, Hydraulic conductivity in soils irrigated with wastewaters of differing strengths; field and laboratory studies. Australian J. Soil Res., 37(2) (1999) 391–402.
[34] S. Milani, Applied Landscape Irrigation Design. Challenger TAFE Press, 2004.
[35] E.L. Anderson, I. Pepper and W.R. Kneebone, Reclamation of wastewater with a turf filter: I. Removal of nitrogen. J. Water Pollution Control Fed., 53 (1981) 1402–1412.

Appendix

Scheduling formulae (from Milani [32])

Terms

W_{tot} — Total available water capacity, mm/m
δ_{root} — Design root zone
μ_{ad} — Management allowable deficit
C_c — Crop factor
E_{Apan} — Average daily A-pan evaporation, mm/d
Q — Application rate, mm/h
η_{irrig} — Irrigation efficiency

Formulae

- Net water requirement

  $(Q_{net}) = W_{tot}\,\delta_{root}\,\mu_{ad}$

  Assuming: W_{tot} in a sandy loam = 120 mm/m, δ_{root} = 0.25 m, μ_{ad} = 50%.
  ΔQ_{net} = 15 L m^{-2}

- Gross water requirement

  $(Q_{gross}) = Q_{net} / (\eta_{irrig}/100)$

  Assuming: η_{irrig} of sub-surface dripline = 100%.
  ΔQ_{gross} = 15 L m^{-2}

- Irrigation interval

  $(T, \mathrm{d}) = Q_{\mathrm{gross}} / (E_{Apan}\, C_c)$

  Assuming: C_c of couch grass = 0.5,
  E_{Apan} in Northam in January = 10 mm
  ΔT = 3 d

- Duration of irrigation

  $(\tau_{irrig}, \mathrm{h}) = Q_{gross}/Q$

  Q is product specific, depending on dripper and line spacing
  $Q_{Netafim}$ = 10 L/h/m^2
  $Q_{Triangle}$ = 10 L/h/m^2
  Q_{Kiter} = 13 L/h/m^2
  $Q_{Plastro}$ = 11.85 L/h/m^2
  $\Delta\tau_{irrig\ Netafim}$ = 1 h 30 min
  $\Delta\tau_{irrig\ Triangle}$ = 1 h 30 min
  $\Delta\tau_{irrig\ Kiter}$ = 1 h 9 min
  $\Delta\tau_{irrig\ Plastro}$ = 1 h 16 min