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Decentralised Wastewater Treatment and Recycling in Urban Villages

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Abstract: Decentralised wastewater recycling and irrigation systems have been established with industry partners in Perth urban villages. The project is now monitoring and evaluating these systems for performance and reliability to meet regulatory standards, effects on soil and vegetation, pathogen disinfection, nutrients prevented from infiltration to groundwater or infiltrated and recycled, maintenance issues of the systems and the effective amount of scheme and bore water saved in the long term. Three trial sites were established for the Premier's Water Foundation (PWF) (Bridgewater Lifestyle Village 389 household greywater recycling; Timbers Edge Resort Village 260 houses to common greywater recycling; Banksia Tourist Village 162 park homes to common wastewater treatment) The research team continues to conduct research on other promising sites (Somerville Ecovillage with 104 houses on dry composting toilets and greywater recycling and Tuart Lakes Lifestyle Village with 415 park homes to common wastewater treatment). This paper provides an overview of the results to date from five research topics: completed are a new regulatory framework, a technical elements model, and a new water balance and efficiency rating tool. For the fourth topic, trials found that mosquito control measures are effective. Fifthly, early monitoring results for a "zero emissions nutrients" (ZEN) model for urban land developments are promising with nutrient leaching within prescribed limits.

Keywords: Decentralised, wastewater, recycling, irrigation, urban villages

INTRODUCTION

Perth, Western Australia's largest city is under increasing pressure to implement a more sustainable means of water supply and use. The coastal city is expanding rapidly in both population and geographical size (EPA, 2005), while annual rainfall is variable and gradually decreasing (WC, 2005). On top of the supply issues Perth is continuing to implement a centralised approach to wastewater sanitation, which combines many wastewater streams before treatment and disposal to ocean outfall (EPA, 2005). This creates an open cycle system that has many sustainability issues including inefficient use of potable water supplies, loss of freshwater resources and nutrients, pollution of the receiving water bodies, as well as the need for high-energy infrastructure (Ho and Anda, 2004). In response to Perth's water supply concerns the Western Australian Government implemented a State Water Strategy in February 2003. This paper reports on the early results of demonstration projects of decentralised wastewater recycling in urban villages in Perth, Western Australia.

This project is monitoring and evaluating decentralised wastewater recycling and irrigation demonstration projects operating with design flow rates of 20 to 200 kl/day (40 to 400 houses). The project is focussed on the Perth metropolitan area and Peel Region over the period 2005-08.

The demonstration projects involved establishing, monitoring and evaluating decentralised wastewater treatment, recycling and irrigation systems with industry partners in Perth urban villages. The results will seek to demonstrate performance and reliability to meet regulatory standards, effects on soil and vegetation, pathogen disinfection, nutrients prevented from infiltration to groundwater or infiltrated and recycled, maintenance issues of the systems and the effective amount of scheme and bore water saved in the long term.

This paper provides an overview of the findings from five related research topics: 1) a new regulatory framework, 2) a technical elements model, 3) a water balance and efficiency rating tool, 4) mosquito monitoring in greywater wetlands, and 5) a "zero emissions nutrients" (ZEN) model for urban land developments.

OBJECTIVES

The technical objectives are as follows:

i. Monitor and evaluate decentralised wastewater recycling and irrigation demonstration projects operating with design flow rates of 20 to 200 kilolitres per day (Strang, 2008).

ii. Review of prescribed chemical and microbiological standards for domestic non-potable residential and municipal irrigation uses, and how these can be most reliably sustained in decentralised wastewater treatment systems for urban villages. (Radin, 2008)

iii. Verify the claims of medium sized, new generation wastewater treatment plants in relation to high quality treatment, no public health risks and no environmental risks in reuse applications. (Jamieson, 2006)

iv. Determine which management protocols for decentralised wastewater treatment plants are most appropriate. (Jamieson, 2006 and Strang, 2008)

v. Evaluate the effects of chemical and microbiological constituents on groundwater from the irrigation of urban landscapes. (Radin, 2009)

vi. Determine the feasibility of a "zero emission nutrients" urban village. (Radin, 2009)

vii. Determine whether reclaimed water can be effectively used for localised food production in peri-urban villages. (Byrne, 2008)

viii. Outline the potential benefits for government to invest in decentralised water supply and wastewater systems, and determine the triple bottom line implications of such investment. (Strang, 2008)

ix. Compare results with domestic water use studies undertaken by Water Corporation to determine actual scheme and groundwater quantity savings to be realised with combined water conservation and effluent recycling schemes in urban villages. (Hunt, 2006)

Findings from research into these objectives is provided in the following sections. Firstly, the case studies are described below in more detail.

CASE TRIAL SITES

The trial sites are as follows:

- Bridgewater Lifestyle Village (National Lifestyle Villages Pty Ltd) at Erskine, City of Mandurah, under construction with 389 onsite household greywater recycling systems for yard irrigation;
- Timbers Edge Residential Resort (Peel Waters Pty Ltd) at Dawesville, City of Mandurah, under construction with common greywater collection from 260 houses to a constructed wetland treatment system for irrigation of Public Open Space (POS) with below ground piping and pump stations installed and wetlands constructed;
- Banksia Tourist Village at Hazelmere, City of Swan, where all wastewater from the existing 162 park homes, caravans and ablutions facilities in a village setting were collected to a new on-site MBBR treatment plant (which has capacity to also receive effluent from a future proposed 143 park homes) from where secondary treated effluent is either discharged to the former sewage lagoon or a trial dripline irrigation area;
- Tuart Lakes Lifelyle Village (National Lifestyle Villages Pty Ltd), City of Rockingham, planning approved where all wastewater from 415 manufactured park homes will be

collected at a central treatment unit from where secondary treated effluent will be irrigated via dripline tubing to the village parks and gardens.

- Somerville Ecovillage (Greenedge Projects Pty Ltd) at Chidlow, Shire of Mundaring, <u>in final design stage</u> where all 104 houses will be fitted with dry composting toilets, optional greywater recycling systems and at least all kitchen greywater will go to cluster scale (x10) greywater recycling systems.

FINDINGS IN EACH RESEARCH TOPIC

This section describes results to date on the 5 research topics listed above.

DeWaTARS

The assessment of the case studies has led to the development of a new regulatory framework known as Decentralised Wastewater Treatment and Recycling Systems or DeWaTARS. The framework focuses on six main criteria that need to be assessed when initiating a decentralised wastewater recycling project:

a) The ability to develop and implement a risk assessment and management plan;
b) Public Liability insurance cover for residents and Workers Liability insurance for employees undertaking maintenance work on the system;
c) Management infrastructure needs to be in place to ensure that timely and efficient management of the system occurs;
d) Ability to monitor the system;
e) Technical ability to maintain, operate and update the system;
f) A cost recovery mechanism that is fair and equitable.

The key criteria were identified to ensure that public and environmental health is maintained (Strang, 2005). The DeWaTARS framework focuses on closing the water cycle loop at a local scale with localised reuse of treated wastewater, initially for private and public open space irrigation, with scope for other reuse applications such as indoor toilet flushing, should the current legislation change. The framework also provides regulators and developers with a means of assessing application details that ensure: on-going maintenance and monitoring controls are in place; the integrity of the technology is sound; that there is a fair and equitable pricing system in place; and that a risk assessment and management plan is completed and implemented for both the construction and operating phases.

By using the DeWaTARS framework regulatory authorities can provide guidance to developers with simple parameters that can apply to any treatment and recycling system that is independent from the centralised wastewater system; involves either multiple connections to the chosen technology or the central management of several on-site systems; ensures that the treated wastewater is used for local reuse whether that be for in-house, ex-house or for public open space irrigation; has centralised management by a wastewater service provider, who ensures operation, regular maintenance and monitoring; can include any technology that has been approved by relevant regulatory authorities.

Technical Elements Model

For decentralised wastewater recycling onto public open space within urban villages there are Public health; Environmental and Management system requirements. Meeting these technical requirements in the best possible manner also includes a requirement to select the most appropriate wastewater treatment technology. This was determined as being the fourth element required to achieve reliable management systems and improved protection of public health and the environment.

Prior to the development of any site the characteristics of the wastewater recycling system and the receiving environment must be established. One of the most important environmental issues surrounding wastewater recycling is contamination through excess nutrients. The characteristics of the wastewater recycling system that need to be considered are:
- General configuration;
- Scale of collection; and
- Recycling system components (appropriate technologies).

General configuration

There are three possible wastewater type configurations for village scale wastewater recycling, including:

- Sewage (blackwater) recycling (independent of deep sewerage network);
- Greywater recycling (with blackwater to deep sewerage);
- Sewer mining (deep sewerage connection still required).

 The first two of these are represented within the first three case studies selected as part of this research; sewer mining is yet to be trialled in Western Australia. Selection of these wastewater configurations may only sometimes be governed by legislation in Western Australia. For example the Perth Metropolitan Sewerage Policy may specify that deep sewerage connection is required if the infrastructure is available at the site, in which case an investigation of sewer mining or greywater recycling can be considered.
 The general configuration of the wastewater recycling system should be considered in the 'feasibility study' step of the implementation process.

Scale of collection

The scale of collection is a major consideration for decentralised wastewater recycling systems. Different wastewater treatment systems are suited to different wastewater flows, therefore making it an important part of appropriate technology choice. Also, the scale will alter the values of certain characteristics, for example capital or management cost per connection. Three different scales of collection have been identified as Lot (individual house); Cluster (medium cluster of houses); and Village (large residential developments). These scales are presented in Table 1.

Table 1: The three scales of decentralised wastewater recycling

Scale of collection	Acceptable size			Typical size		
	(kL/day)	No. homes (connections)	No. Inhabitants	(kL/day)	No. connections	No. Inhabitants
Lot	1.8	1	1 - 10	~0.4	1	~3
Cluster	3.6-50	2-100	10-250	~20	~40	~120
Village	50-1000	100-2000	250-5000	~200	~400	~1,200

 Table 1 identifies the progression used to define the three different scales. The acceptable size figures are very broad and represent what is acceptable within each scale. The typical size figures were estimated based on a range of case studies and available treatment technology

information. The typical figures were used to calculate the capital and management cost variations between different scales of collection.

The scale of collection is not as clear-cut as Table 2 indicates. A residential development may have a total wastewater flow of 200kL/day, however due to design layout or geographic features it may be preferable to implement two or more cluster systems rather than one village system. As lot scale collection of the wastewater is not suitable for public open space irrigation it has not been included in this research.

Table 2: The general concept behind the scale of collection selection

Indicated wastewater collection size	Wastewater treatment scales
1 home	Lot
Less than 50kl/day	Cluster scale
More than 50kL/day	Village scale

Recycling system components

The three recycling system components include:

- Core treatment – the initial treatment system that will typically provide the primary and secondary treatment;
- Additional treatment components – any additional systems and processes that provides extra quality enhancement of the wastewater such as tertiary filters and additives;
- End application – which refers to the public open space irrigation method

Choosing the 'core treatment' process can often be difficult as there are many technology types and considerations to assess. The findings from our earlier research were used to develop a model for selection of suitable decentralised wastewater recycling systems. The model aims to determine the associated technical requirements and appropriate technologies, referred to as the technical elements, to meet those requirements based on specified characteristics of the situation. The model is therefore titled the Decentralised Wastewater Recycling for Public Open Space of Urban Villages Technical Elements Model or 'Technical Elements Model' (TEM) for short.

The process of implementing the Technical Element Model can be summarised by the following progression:

1. General System Configuration (feasibility study step)
    a. Sewage recycling; or
    b. Greywater recycling; or
    c. Sewer mining.
2. Scale of Collection (subdivision design step)
    a. Lot (not included); or
    b. Cluster; or
    c. Village.
3. Public Health Requirements (system design step)
    a. Type of wastewater
        i. Greywater; or
        ii. Sewage.

b. End use
    i. Spray irrigation; or
    ii. Sub-strata irrigation; or
    iii. Sub-surface irrigation.
c. Water quality
    i. Class A; or
    ii. Class B/C. (or equivalent log reduction)

4. Environmental requirements (system design step)
  a. Design hydraulic loading
    i. Well drained; or
    ii. Moderately drained; or
    iii. Poorly drained.
  b. Soil and Groundwater analysis (nutrient management)
    i. A,B,C or D (vulnerability category)
  c. Downstream surface waters and buffer zones
  d. Other receiving environments

5. Appropriate technology selection
  a. Recycling system components
    i. Core treatment
    ii. Additional treatment
    iii. End use

6. Management system requirements
  a. Department of Health
    i. Site and soil report
    ii. System design report
    iii. Operation and maintenance plans
    iv. Monitoring plans
    v. Contingency plans
  b. Department of Water
    i. Nutrient irrigation and management program;
    ii. Contingency plans;
    iii. Detailed site and soil analysis
    iv. Nutrient inputs and outputs from the site; and
    v. Expected seasons; nutrient uptake by the plant species being irrigated

Appropriate Technology Database

In order to make the technology selection process easier a Decentralised Wastewater Treatment Technology Database has been developed. It includes over 150 sourced products from both Australia and overseas in the following categories: Aerobic treatment units; Sand, soil and peat filters; Composting systems; Ponds and constructed wetlands; Anaerobic digestion; Physico-chemical systems; Advanced filtration; Urine separation and treatment; and others. The various products in each category are grouped into subcategories based on the different treatment processes. The categories and subcategories are provided with process descriptions, comparative evaluation system and suggestions for application. The database helps to provide a more straightforward and simplistic means of decentralised wastewater system technology choice, and can be used by land owners, developers and associated governing bodies to reduce the complications associated with developing decentralised wastewater systems.

LaDeRS-H20

A rating tool has been developed for determining the water use performance efficiency of land developments. (It has been named LaDeRS-H20.) The rating score also indicates how effective the land development is in implementing decentralised water systems. Land developments can draw supply from scheme water and dispose of wastewater through a centralised sewerage system, or they can rely on rainwater harvesting and reuse water entirely within the land development, or anywhere in between from a centralised to a decentralised system. The rating tool quantifies the volumes of water drawn from all sources and wastewater disposed or reused through all routes, compares these with best practice water use volumes and arrives at a score out of 10 (equivalent to best practice) for the land development. The algorithm for the rating tool is implemented using Excel workbook/worksheets prompting users to enter required input values. Application to four of the above case study land developments was conducted. The rating tool assists land developers in improving the water use efficiency of the development, in promoting their water efficient estate to consumers, for consumers in choosing between alternative estates, and for regulators in facilitating more efficient use of water for land development.

 The rating tool provides a means of measuring progress from a centralised water system to a decentralised water system. If the best practice conditions for a land development are set with zero flow of water from scheme water and zero flow of wastewater to a centralised sewerage system, then the score indicates how well the land development is in performing as a decentralised system. The score is a quality measure with the higher score indicating better achievement. The rating tool highlights the need to consider the broader questions of whether it is realistic to set best practice as equivalent to disconnecting to (or independent of) a centralised water and wastewater systems. In water deficient areas rainfall precipitation on the land development may not be sufficient, and water will have to be imported. Even in areas where rainfall is adequate there is the question of how much water should be retained within the land development area, and whether water is released through run-off to local stream outside the land development or through groundwater flow. In this regard there is an imperative in mimicking nature, i.e how water would have behaved in the natural uncleared area prior to any development. As the rating tool is applied to more case studies with differing local conditions we will gain greater experience that will provide guidance on how to apply it to general and particular situations.

Monitoring Mosquitoes in ETTs

Subsurface flow constructed wetlands are used at the Bridgewater Lifestyle Village (BWLV) as a means of reducing nutrient flows to groundwater from household greywater systems and are referred to at this site as Evapotranspiration Trenches (ETTs). The metropolitan region of Perth to Mandurah is situated on the Swan Coastal Plain which is generally comprised of sandy soils throughout and groundwater is often close to the surface. Under local regulations greywater recycling systems cannot normally be used in areas within 500 mm of groundwater. For the low-lying land of BWLV where 88 of the 389 households are located the ETTs were specifically designed as the nutrient control solution to be coupled with the garden greywater recycling system. Residents are also provided with induction on the greywater systems, information sessions on operation and maintenance, and low nutrient, environment-friendly detergents from the village management.

 The goal of this study was to determine the mosquito breeding potential of these ETTs. Data was collected on water level changes and abundance of mosquito larvae in the ETTs as well as the abundance of adult mosquitoes in the vicinity of the ETTs. Captured mosquito species were identified. Vertical monitoring pipes were placed in the ETTs to allow water level and

larval sampling. Adult sampling utilised a dry ice trap and was conducted both at the BWLV and a nearby natural wetland.

Water levels in all of the three trial ETTs remained under the gravel surface during the monitoring period. No mosquito larvae were observed in any of the samples taken from the ETTs. The results of adult monitoring showed that mosquito abundance was clearly higher at the natural wetland compared to the BWLV site. Captured mosquito species were the same at both adult monitoring sites.

The results indicated that the ETTs did not produce mosquitoes during the sampling period. Alternative breeding grounds were available for all of the species caught. In general the ETTs are very unlikely to produce mosquito as long as the water levels remain under the gravel surface. In case of flooding, prolonged flooding would be required for adults to emerge from the systems. Such flooding is unlikely as long as the ETTs are installed and maintained appropriately.

ZEN Model for Land Developments

Research has commenced into the development of Zero Emission Nutrients (ZEN) model for urban residential land developments. The aforementioned case studies are being monitored with lysimeters under treated effluent irrigation areas and control samples are being taken from sampling bores at the perimeters of the developments. Over time it will be determined if the following measures are adequate to redress excessive nutrient leaching to the environment:

1. Bridgewater Lifestyle Village
    a. Direct application of greywater from houses to subsurface irrigation of individual gardens,
    b. Use of ETTs for additional nutrient removal in low lying areas within 500 mm of groundwater;
    c. Use of water sensitive, native garden design for all homes and public open space;
    d. For supplementary irrigation of POS use of horizontal bores to avoid over abstraction from shallow freshwater lens to saline water below;
    e. Retention of mature trees and use of native species for revegetation
    f. Establishment of vegetated road side verges and buffer areas
    g. Limits on earthworks
    h. Solar passive building design and lot layout
    i. Water sensitive design principles for stormwater drainage
    j. Support, promotion and bulk purchase of low nutrient detergents and environmentally friendly cleaning products for residents
    k. Advocacy of no fertilisers for gardens
    l. Workshops for residents on nutrient management
2. Timbers Edge Residential Resort:
    a. Collection and treatment of greywater from houses and resort buildings for on-site irrigation of public open spaces;
    b. Use of central constructed wetlands with additional dosing features to reduce nutrient levels;
    c. Use of water sensitive, native garden design for all homes and public open space;
    d. For supplementary irrigation of POS establishment of multiple bores to carefully abstract groundwater as top-up to greywater irrigation system to POS;
    e. Retention of mature trees and use of native species for revegetation
    f. Establishment of vegetated road side verges and buffer areas
    g. Limits on earthworks
    h. Solar passive building design and lot layout

i. Water sensitive design principles for stormwater drainage
j. Support and promotion of low nutrient detergents in households
k. Support and promotion of slow release fertilisers for gardens
l. Workshops for residents on nutrient management

Monitoring of nutrients within and without the settlement boundary will determine if it is possible to use local superficial aquifers as a store for both nutrients and water and subsequent irrigation. The degradation and leachate of greywater was investigated in a lysimeter study. The lysimeter is a tool to capture the movement of water and chemicals through soil profile. Table 3 presents measured values of chemical parameters and nutrients from greywater effluents and leachate from monitored greywater reuse sites. Average $\pm$ standard (mg/L) error concentrations of greywater effluents and leachates from four selected household around Perth, Western Australia are presented. Samples were taken in October and November in 2008 and January and February in 2009. These are the late spring and dry summer months when irrigation is typically required.

Table 3: Results of greywater effluents and leachates from four selected households.

Parameter	House A		House B		House C		House D	
	Effluent	Leachate	Effluent	Leachate	Effluent	Leachate	Effluent	Leachate
pH	7.31±0.22	7.12±0.01	7.80±1.17	7.21±0.41	7.12±0.01	6.90±0.61	6.95±0.37	7.04±0.28
Conductivity μS/cm	178±105.37	410±296.98	311±336.88	111±15.56	400±0.00	573±392.02	100±0.00	329±338.63
BOD_5	60±10.00	11±1.30	92±2.52	32±10.40	120±10.00	24±3.50	19±1.00	77±2.50
TSS	60±3.29	90.02±4.2	68±9.18	113.67±29.2	81±7.09	131.72±53.4	60.11±0.58	92.52±32.4
TDS	113.92±1.05	262.4±0.29	119.04±0.3	71.04±0.15	256±0.00	366.72±3.9	64±0.00	210.56±3.9
NO_3 as N	0.02±0.01	0.08±0.04	0.02±0.01	0.26±0.04	0.06±0.03	0.41±0.41	0.08±0.00	0.90±0.71
NH_4 as N	1.96±0.62	1.28±0.11	1.53±0.44	1.87±0.89	0.47±0.10	3.14±1.38	0.42±0.04	2.71±1.23
TKN as N	1.48±0.15	0.15±0.81	1.53±0.44	0.44±0.21	20.67±2.08	6.67±0.51	12.23±0.40	14.51±0.75
P	0.29±0.13	0.71±0.28	2.47±1.63	4.73±1.17	2.32±0.24	4.40±1.26	0.30±0.20	4.08±1.57
Boron	0.59±0.03	0.44±0.07	0.71±0.04	0.55±0.04	0.17±0.08	0.10±0.01	1.08±0.01	0.91±0.34

The results in Table 3 shows that chemical parameters were within acceptable levels (ANZECC, 2000). for irrigation with laundry and bathroom greywater such that these will not be hazardous to soils and groundwater.

CONCLUSIONS

Environmental Technology Centre at Murdoch University was funded to conduct "Demonstration of Decentralised Wastewater Recycling in Urban Villages" which was funded by the Premiers Water Foundation of the Government of Western Australia. There are substantial findings from the research to date.
The assessment of the case studies has led to the development of a new regulatory framework known as Decentralised Wastewater Treatment and Recycling Systems or

DeWaTARS. The framework includes six main criteria that need to be assessed when initiating a decentralised wastewater recycling project.

The Technical Elements Model (TEM) has been developed to determine the technical requirements and appropriate technologies for Decentralised Wastewater Recycling for Public Open Space of Urban Villages. In order to make the technology selection process easier a Decentralised Wastewater Treatment Technology Database was developed with over 150 sourced wastewater treatment products.

The LaDeRS-H20 rating tool has been developed for determining the water use performance efficiency of land developments.

Monitoring of small constructed wetlands at one of the demonstration sites has shown that if these are specifically designed for effluent treatment and maintained correctly then they can be used in localized reuse schemes without the risk of promoting mosquito breeding.

Research methods and materials are in place at the trial sites for ongoing monitoring of nutrients within and outside the settlement boundary to determine if it is possible to use local superficial aquifers as a store for both nutrients and water and subsequent irrigation. Monitoring results were compared with the water quality recommendations for irrigation stipulated in ANZECC guidelines (2000). This showed that chemical parameters were within acceptable levels for irrigation with laundry and bathroom greywater such that these will not be hazardous to soils and groundwater.

ACKNOWLEDGEMENTS

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