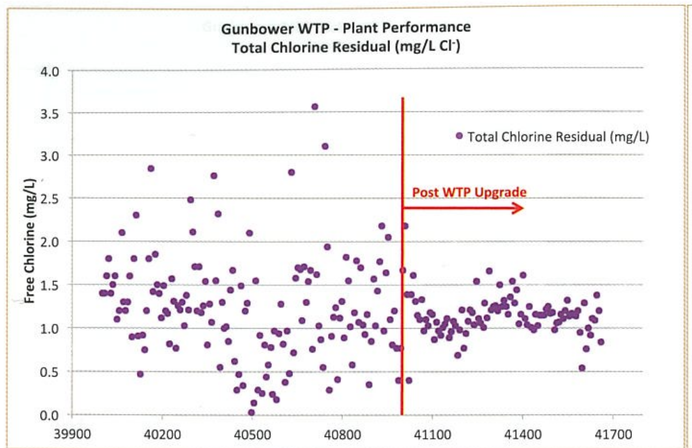

Figure 14. Gunbower WTP – before and after upgrade – total chlorine residual (mg/L).

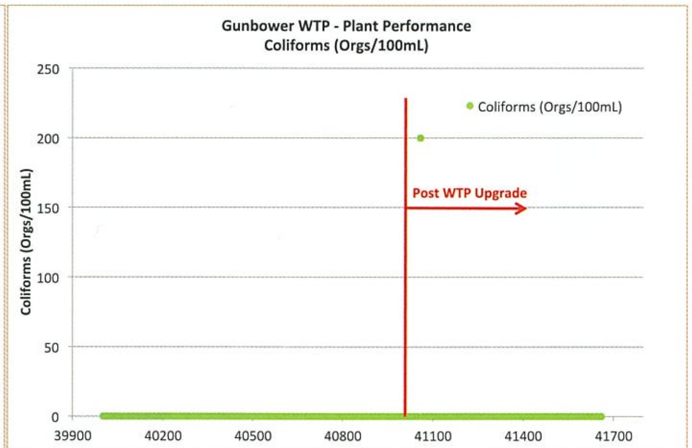

Figure 15. Gunbower WTP – before and after upgrade – total chlorine residual (mg/L).

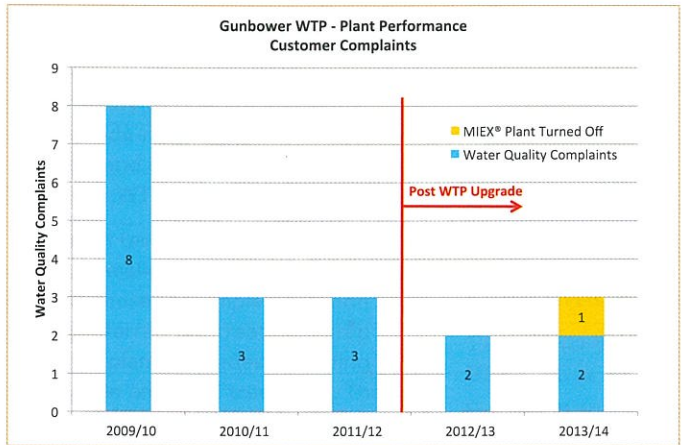

Figure 16. Gunbower WTP – before and after upgrade – customer complaints.

The data shows that coliforms weren't an issue in the distribution system prior to the upgrade. This is most likely due to the relatively higher chlorine doses used before the plant upgrade, which prevented any coliform formation. It is clear from the free and total chlorine residuals that the plant upgrade has provided better control of the disinfection process, resulting in consistently lower free chlorine residuals, without any risks of increased coliforms in the product water.

A comparision of customer complaints before and after the WTP upgrade was conducted, and results were calculated for the 12-month periods before and after the upgraded WTP was commissioned (e.g. from 1/4/2012 to 30/3/2013).

Comparison of historical customer complaints shows (Figure 16) that there has been a slight reduction in customer complaints of the treated water quality after the WTP upgrade. It is important to note: a customer complaint was received during the 2013/14 period (i.e. February 2014), which was after the MIEX® Plant was shut down to reduce ongoing operational costs.

SUMMARY

These results indicate that the upgraded Gunbower WTP is able to produce treated water that will consistently meet the current *Australian Drinking Water Guidelines* (ADWG) and Victoria's *Safe Drinking Water Regulation 2005* (i.e. THMs < 250ug/L). These results can be achieved consistently, even during worst-case raw water quality conditions, which can be experienced due to periodic flooding events.

In addition, the upgraded Gunbower WTP should also meet any potential future revisions to the standards as the treated water produced meets the current USEPA DBP limits (i.e. 80 ug/L).

CONCLUSION

The final treated water after installation of the MIEX® Technology, together with post-treatment processes, now easily complies with existing drinking water regulations and the upgraded treatment plant will ensure compliance in years to come.

It is expected that the improved drinking water quality will result in increased use of water for drinking in the Gunbower township, as the water quality will be suitable for more domestic applications. Many surrounding customers without piped water supply are reliant on unsafe rainwater tanks for drinking water; and they are now travelling to Gunbower to collect their drinking water.

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DECENTRALISED SEWERAGE SERVICING – EVALUATION OF A YELLOW WATER, GREYWATER AND BLACKWATER TRIAL

Review of the Kinglake West Sewerage Project by Yarra Valley Water in Victoria

R Fernando, S Cook, R Narangala, F Pamminger, A Gellie, A Sharma, R Wrigley

ABSTRACT

The Kinglake West Sewerage Project was undertaken by Yarra Valley Water (YVW) to determine whether it was possible to deliver a more sustainable sewerage solution in a developed, unsewered 'backlog' area, as identified in theoretical studies. Many innovative concepts and products were tested as part of the project including urine-diverting toilets, yellow water harvesting, greywater systems and STEP tanks.

The post-implementation review found that, although environmental improvements were delivered, they were not as high as predicted and the application of new concepts came at a higher cost.

INTRODUCTION

YVW serves over 1.7 million people through a water supply network of 9,500km and a sewer network of over 9,000km, with associated pumping, storage and treatment works.

In addition to providing services to new developments, YVW has a significant Sewerage Backlog Program with more than 17,000 homes in suburban and peri-urban fringes that are currently serviced by septic systems. In many cases these septic systems are failing, posing an environmental and public health risk. In 2005, CSIRO and RMIT were commissioned by YVW to undertake research into more sustainable approaches for servicing these areas rather than conventional reticulated sewerage systems. The research proved that it was theoretically possible to deliver more sustainable alternate solutions (Sharma *et al.*, 2006, Sharma *et al.*, 2010). The results showed that alternative solutions could offer the following benefits when compared to a conventional gravity servicing approach:

- Economic savings of up to 20%;
- Increased reliability in water supply from 90% to 100%;
- Reduced wastewater discharges by up to 50%;
- Reduced nitrogen loads to the STP by up to 80%;
- Reduced greenhouse gas emissions by 30%.

The aim of the Kinglake West project was to put this theory into practice in a trial. The need for the project was also driven by the fact that it might be more economical to service small communities with decentralised approaches and also by the potential value in recovering the nutrients in wastewater for food production.

KINGLAKE WEST CASE STUDY

Kinglake West is located on Melbourne's urban fringe, approximately 45km north-east of the CBD (Figure 1). An area of 74 residences was selected for the study. These properties did not have reticulated water or sewerage and were scheduled for servicing in the future as part of the YVW Sewerage Backlog Program.

Figure 1. Kinglake West case study location.

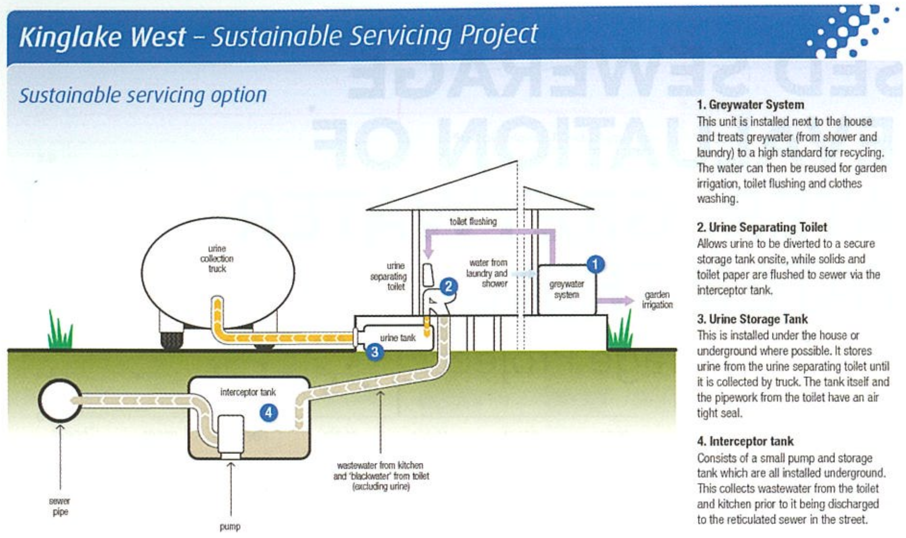

Figure 2. Kinglake West household servicing configuration.

Aside from the need for better sewage management, the study area was selected because it is remote from existing infrastructure and is difficult to service conventionally. The area is adjacent to an environmentally sensitive national park that will benefit from better sewage management, and is close to agricultural areas that are potential end users for recycled water and other products.

YVW sought to achieve three main objectives at Kinglake West:

- Enhance the environmental, public and waterway health through innovative wastewater management;
- Identify a solution with lower community cost;
- Demonstrate the benefits of a sustainable alternative wastewater servicing approach for a smaller community to the wider water industry.

After careful assessment of a range of options against the project objectives and a multi-criteria assessment considering economic, environmental and social impacts, the preferred servicing solution comprised the following (see Figure 2):

- Greywater treatment systems on each property producing recycled water for toilet flushing, clothes washing and garden irrigation;
- Urine-diverting toilets with yellow water being collected and reused for agricultural purposes;
- On-site septic tanks with blackwater being transferred via a pressure sewer system utilising septic tank effluent pumps (STEP);
- Low energy/complexity sewage treatment plant (STP) to treat the effluent further before irrigating surrounding land.

URINE-DIVERTING TOILETS

Urine-diverting toilets (UDTs) are still relatively new to Australia, having been installed at only a handful of pilot sites. Kinglake West is the first existing community to have UDTs installed. A total of 30 UDTs were installed at the 23 households that elected to participate in the trial.

UDTs are designed to collect faecal matter at the back of the toilet bowl, while urine is diverted to the front. The faecal matter is either flushed to the sewer or is stored and composted.

A number of UDT models were assessed during the selection process, including the Wostman Ecoflush, Dubbletten, Sealskin and Gustavsberg. The Wostman Ecoflush was selected on the basis of its similarity to existing Australian toilets, user-friendliness, ease of maintenance, appearance, flush volume and cost.

However, testing against Australian standard AS 1172.1 – 2005 *Water Closets* later showed that the Wostman UDTs used significantly greater volumes for flushing than indicated by the manufacturer (Table 1).

YELLOW WATER AND AGRONOMIC TRIAL

The case for recovering nutrients from urine is based on the premise that urine only constitutes 1% of domestic wastewater flow, but constitutes around 80% of the nitrogen and 45% of the phosphorus. Recovering the urine offers the following benefits (Fewless *et al.*, 2011):

- Reduced environmental contamination from nutrients;
- Energy savings at the STP;
- More efficient anaerobic digestion of blackwater;
- Water conservation;
- Reduced demand for phosphate rock fertiliser, which is a depleted and non-renewable resource (Cordell *et al.*, 2009).

At Kinglake West, yellow water was collected in a 1,100L polyethylene tank on each property, which was designed to provide about 60 days' storage for a household of four people. In practice, the tanks were emptied at shorter intervals to guard against the potential of an overflow. Yellow water was pumped from each property into portable 1,000L plastic 'cubes', since these were easily transportable and could be 'batched' for storage.

A nearby turf farm in Kinglake West agreed to trial the application of yellow water as a fertiliser substitute. Turf production is a good candidate for yellow water application since it requires high and regular rates of fertiliser application and is not a food crop, hence minimising the risks to human health. Moreover, turf grass is a resilient crop that can tolerate the higher salinity levels found in yellow water.

YVW engaged agronomic scientist Roger Wrigley, of the University of Melbourne, to design and supervise the agronomic trial. In order to determine the application rate, yellow water from 40 storage cubes was sampled and analysed. This revealed low nutrient concentrations compared to expected values from a literature review (Table 2). This was largely due to the high flush volumes.

Table 1. UDT performance against specs.

Performance Criteria	Manufacturer's Specification	Actual Performance
'Urine flush' volume	0.2 litres	1.3 litres
Full flush volume	2.5 litres	5.1 litres

Table 2. Yellow water average nutrient concentrations versus expected concentrations.

Parameter	Average Values in Kinglake Yellow Water*	Typical Urine Values in Literature (Wrigley, 2010)
Total Nitrogen (mg/L)	1,581	4,000–8,000
Total Phosphorus (mg/L)	102	200–500
Potassium (mg/L)	290	1,000–3,000
Conductivity (uS/cm)	10,685	27,000

** Average of samples from 40 cubes, ranging in age from 4 days to >12 months*

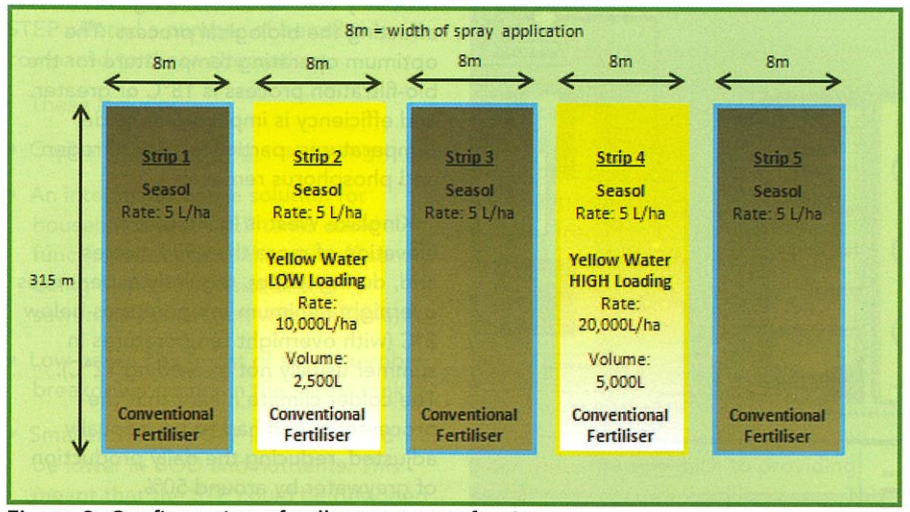

Figure 3. Configuration of yellow water turf strips.

Table 3. Comparison of yellow water N:P:K with commercially available fertilisers.

Liquid Fertiliser	Conductivity* (uS/cm)	N:P:K ratio (% w/v)
Blood and Bone	1,234	5.0: 0.9: 1.1
Seaweed and Fish Puree Complex	687	3.5: 0.6: 0.7
Seaweed Extract (SEASOL)	341	4.6: 1.2: 3.1
Kinglake Yellow Water	10,685	0.15: 0.01: 0.02

**When diluted for application*

Figure 4. Harvested turf strips (left), and test strip and irrigation system.

Yellow water was also compared with commercially available fertilisers in terms of nutrient content. The N:P:K ratio (nitrogen: phosphorus: potassium) is commonly used to represent the available nutrients in fertiliser by weight. It can be seen that, when compared to other fertilisers and growth promotants, the yellow water is lower in nutrients and much higher in salinity (Table 3). This highlights that the yellow water from Kinglake West could not be used to entirely replace other fertilisers without salinity being an issue.

The agronomic trial took place over five turf strips of 8m x 315m (0.25 ha each). Yellow water was applied at two different loadings, as shown in Figure 3. The turf farm uses Seasol as a growth promotant in addition to fertilisers, and this practice was continued during the trial.

Yellow water was applied using the same method as Seasol application. For the 'low loading' test strip, 2,500L of yellow water was applied over two months (five applications). For the 'high loading' strip, 5,000L was applied in total. Because of the relatively low nutrient content in the yellow water, high application rates were needed. Since the spray nozzles could only irrigate at a certain rate, the tractor had to travel at a very slow pace, and multiple passes were required. The power take-off driven spray equipment available at the turf farm had a relatively low application rate (15–20 litres per minute) and thus required a lot of operator time.

It was estimated that to apply the recommended 4,000 litres of yellow water to the 0.5 ha trial plot required two hours of operator time per fortnight. This slow application rate caused concerns for the operator due to the labour required – 4,000 litres of yellow water was required to be applied per hectare each fortnight compared to five litres of Seasol.

During application, a strong, unpleasant odour was reported by turf farm staff. Fortunately, the odour dissipated quickly and was not registered beyond the property boundary. Soil sampling indicated that the application of yellow water did not have a significant impact on soil chemistry. There were no visible detrimental impacts on plant health and, based on visual inspection, the yellow water was perceived to yield a grass with better visual quality (i.e. greener). However, further replicated trials at different application rates would be

Table 4. Cost of yellow water and Seasol.

Item	Yellow Water	Seasol
Purchase price	–	$3.8/L
Average collection costs	$650 / kL	-
Transport costs	$15 – 35 / kL	-
Dilution and pumping costs	Included	$0.2/L
Application (labour /equipment)	Not included	Not included
Unit cost	$0.66 / L	$4/L
Volume required per Ha	775 L*	5L
Cost per Ha per application	**$510**	**$20**

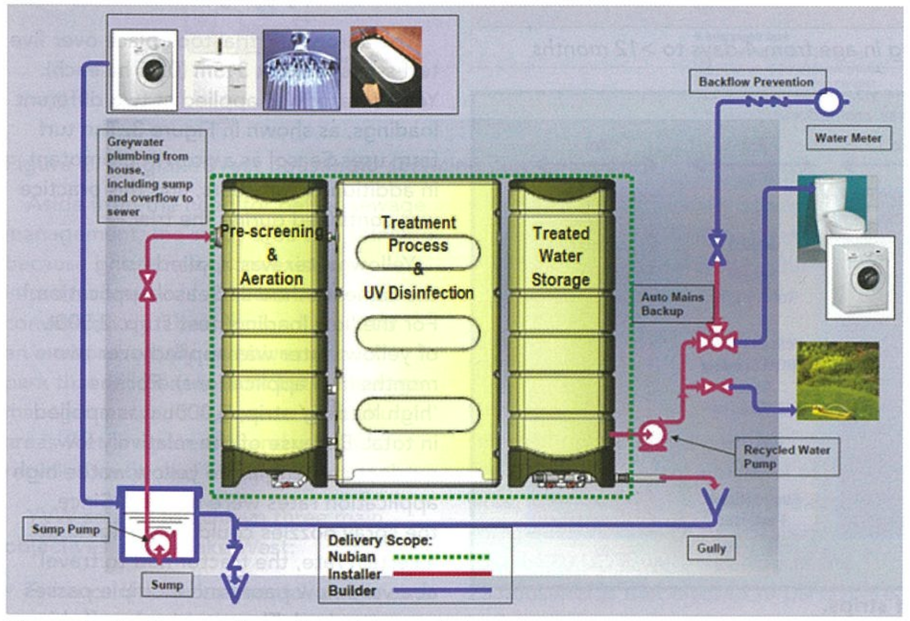

Figure 5. System configuration at house lot.

needed to confirm this. Applying the yellow water as a substitute to growth promotants such as Seasol is currently not cost-effective, as illustrated in Table 4. In addition, salinity impacts would prevent the yellow water from being applied at even higher rates as a fertiliser substitute.

GREYWATER TRIAL AND SYSTEM PERFORMANCE

Greywater is collected from bathrooms and washing machine wastewater and is transferred to a sump well. It is then pumped into the treatment system where it is pre-screened to remove lint, then undergoes bio-filtration and, ultimately, UV disinfection.

The recycled water is stored in a 300L storage and pumped on demand for garden irrigation, toilet flushing and cold water laundry supply. Excess greywater and backwash water from the filter media is fed by gravity to the septic tank. The configuration of the greywater system at the household scale is shown in Figure 5.

A total of 20 greywater treatment units were installed at properties in Kinglake West. The systems have not performed as expected, with the two main issues being poor reliability and power consumption. There were also complaints from some householders concerning the quality of the treated greywater effluent and several odour problems.

Most of the systems experienced frequent failures during and soon after commissioning. Many of the failures were caused by a poorly designed sump pump that accompanied the system. This had to be replaced with a different product. Problems were also experienced with the recycled water pump. Even after the sump and recycled water pump issues were resolved, the greywater systems continued to perform poorly. Monitoring of one system detected two failures over a 30-day period, and lower-than-expected recycled water production most of the time (see Table 5).

The low rate of recycled water production can be attributed to the

Table 5. Recycled water production from monitored greywater system.

Function of Greywater System Results	Days
Supply >80% of demand	3
Supply 50–80% of demand	4
Supply 1–50% of demand	14
Supply 0% of demand	9
Total days monitored	**30**
Times system failed (number)	2

relatively cold climate of Kinglake, affecting the biological process. The optimum operating temperature for the bio-filtration process is 18°C or greater, and efficiency is impacted at colder temperatures, particularly for nitrogen and phosphorus removal.

Kinglake West is located at an elevation of more than 500 metres and, during winter, regularly experiences overnight minimum temperatures below 2°C (with overnight temperatures in summer usually not exceeding 12°C). The colder climate meant that the processer speed had to be manually adjusted, reducing the daily production of greywater by around 50%.

YVW commissioned an independent company to monitor the energy consumption of the water and sewerage system components, including associated pumps. This was carried out at a household occupied by two adults and a child, and reported in Water and Energy Savers (2012). The house was one year old and had WELS 4-star-rated fittings and 3-star appliances. Energy and water flows were monitored over a 30-day period at 15-minute intervals, from November to December 2011. While the monitoring period and sample size are limited, the results are indicative of the performance of the greywater systems overall, and consistent with anecdotal reports and observations.

When compared to the manufacturers' specifications, the energy consumption was over twice that stated in the EPA Victoria Certificate of Approval for the system. The high energy consumption led to some households switching off their greywater systems, further compounding reliability and performance issues (the biological process requires recommissioning after each period of non-operation).

STEP TANKS AND BLACKWATER TRIAL

Each property at Kinglake West has a septic tank that collects blackwater from toilets as well as excess greywater. The blackwater undergoes primary treatment, before being pumped via a pressurised sewer to the STP site. This type of system is also known as a common effluent sewer, or septic tank effluent pumped/gravity (STEP/STEG – although in this case all connections are pumped).

The alternatives to a STEP system were gravity sewers leading to a sewage pumping station, or a pressure sewer system with on-property grinder pumps. STEP offered a number of benefits compared to these alternatives.

These included:

- Capital and operating cost savings;
- An interim sewerage solution for households (the STEP tanks could function as septic tanks with effluent being dispersed onsite until a sewerage connection was available);
- Low odour risk (most of the anaerobic breakdown occurs in the septic tank);
- Smaller STP (the STP influent would be lower in BOD and nutrients. This meant that the STP could be designed with lower organic and hydraulic capacity).

The use of household septic tanks effluent pump (STEP) systems was found to have a number of benefits. In particular, it allowed a staged approach to providing wastewater services. This can assist in transitioning from household

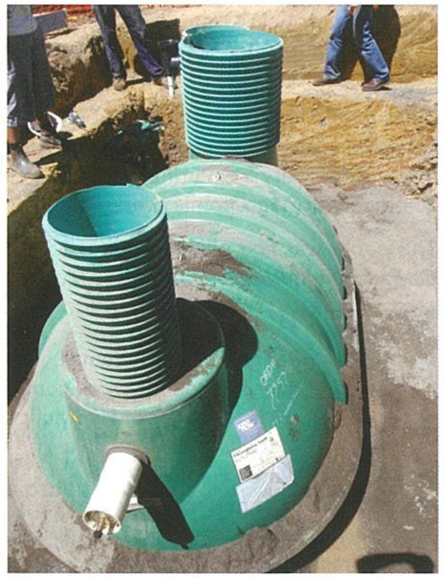

Figure 6. Installation of a STEP tank.

scale septics, which can then be connected to sewerage at a later date. Also, the effluent from a septic tank is of consistent strength and the biosolids are substantially reduced through anaerobic treatment. STEPs offer a number of advantages for decentralised wastewater systems relative to other configurations. They reduce the land footprint required relative to septic tanks that use dispersal fields, while reducing public health and environmental risks. Also, when compared to conveying all wastewater directly to a STP, the use of STEPs can provide direct benefits in reduced capital and operating costs for the sewer collection and STP (Saunders *et al.*, 2010).

Table 6 compares the blackwater from Kinglake West with the characteristics of typical domestic wastewater from Metcalf & Eddy (2003). It shows the impact that urine diversion (in combination with greywater reuse and primary treatment in the septic tank) has on the wastewater composition.

EVALUATION AGAINST PREDICTED BENEFITS

__Economic savings of up to 20%__
The project cost was found to be in the order of 60% more expensive than a conventional approach to providing sewerage services in backlog areas. This is in contrast to the original estimate (based on a desktop analysis) that it would be 20% cheaper. The main reason for the difference was the higher capital costs above what was forecast, as shown in Table 7.

__Increased reliability in water supply from 90% to 100%__ The Kinglake West area does not have reticulated mains water supply, so houses rely on rainwater tanks and groundwater. It was found that previous to this project during low rainfall periods many houses had to have water trucked in to ensure supply.

Therefore, a major objective for the project was to implement measures that would improve water efficiency (such as low-flush toilets) and also augment the primary supply from rainwater tanks (greywater recycling). The CSIRO study by Sharma *et al.* (2006) found that the preferred option should increase residents' volumetric reliability of water supply to 100%, compared to 90% for options without onsite initiatives. Although there have been no reports of residents having to truck water in, meeting this objective was heavily influenced by the post-bushfire rebuilding, where much larger rainwater tanks were installed. The assumed tank volume for estimating reliability was 25kL, while a survey of rebuilt houses found an average of 45kL, with many having much larger rainwater storages. Around 10kL of the storage is quarantined for fire-fighting.

__Reduce wastewater discharges by up to 50%__ The use of greywater systems, UDTs, and low-flush toilets was estimated

Table 6. Comparison of untreated wastewater composition.

Parameter (mg/L)	Kinglake West Blackwater	Typical Domestic Wastewater (Metcalf and Eddy, 2003)*
Total nitrogen	57	70
Phosphorus	8.3	14
BOD 5-day	150	350

** Typical 'high strength' domestic wastewater based on 240L/capita-day (the most similar to Kinglake West flow rates).*

Table 7. Comparison between estimated and realised costs.

Capital cost ($)	Original Estimate (Sept 2009)	Actual Cost (Feb 2012)	Difference
UDTs	182,850	322,858	77%
Greywater systems	414,000	666,942	61%
STP	1,482,458	2,924,575	97%
STEP and pressure sewer system	1,169,064	1,947,067	67%
Community engagement	760,000	306,530	-60%
Design	290,837	880,899	203%
Total	$4.3 million	$7 million	64%

to reduce the volume of wastewater generated at Kinglake West. The capacity of the greywater systems to deliver the benefits intended was impeded by the performance and reliability of these systems in the Kinglake West setting.

Wastewater volumes generated at Kinglake West were around 11.4kL a day for the 32 households connected. This equates to around 130kL of wastewater for each household per year. This is a 28% reduction on the YVW average sewage collected per property of 18 kL/year (2009/10 value).

Reduce nitrogen loads to the STP by up to 80% The analysis of blackwater demonstrated that the source separation of wastewater using urine separating toilets at the household level reduced the nitrogen loads delivered to the STP. It was found that the blackwater concentration and load of nitrogen and phosphorus in Kinglake West influent was substantially less than typical composition of blackwater, based on values in Metcalf and Eddy (2003). The reduction in total nitrogen loads was estimated at 56%, compared to a base case, which meant the original target was not achieved.

Reduce greenhouse gas emissions by 30% The target for greenhouse gas reduction was related to those emissions associated with power generation and supply. This performance objective for the Kinglake West scheme is unable to be evaluated at present as the STP only became fully operational as of December 2013. The assumptions for the reductions in greenhouse gas emissions in comparison to the base case included the impact of the UDT on reducing the nitrogen loads to the STP.

However, as the treatment process selected does not include nitrification, it is not expected that, even if the UDT were operational, diverting the urine (and most of the nitrogen loads) from the wastewater influent would substantially reduce energy demand and associated greenhouse gas emissions. The monitoring of the greywater system trial did show that energy demand for these systems was much higher than manufacturers' specifications. So although the STP performance is yet to be assessed, it is anticipated that predicted greenhouse gas emission reductions will not be achieved.

KEY LESSONS LEARNT

- STEP tanks are a good way of extending wastewater services to small communities. They enable a staged approach to providing the service, while also reducing capital and operating costs for the collection and treatment systems. The connection of septic tanks to a collection network and treatment plant reduces the likelihood of discharge of wastewater contaminants to the environment.
- There is a need to consider the feasibility of alternative water sources on a site-specific basis. If there is insufficient demand for the alternative water source it is unlikely that the costs and management complexity can be justified on other grounds, such as reduced wastewater volumes.
- Technology selection and installation should be staged. Novel approaches such as urine diversion and greywater recycling are immature technologies so there is uncertainty in their performance, maintenance requirements and operating costs.
- Having a streamlined approach with a single party responsible for the installation, supply and maintenance of household systems, such as greywater recycling units, is critical. This would clarify responsibilities for addressing any problems with the systems, be easier for YVW to manage, and provide better customer service.
- Where possible, the technologies associated with source separation of wastewater should be designed and configured to minimise the behavioural change required by households.
- The high establishment costs of household greywater recycling systems, and the complexity of devolving some management and O&M responsibilities to householders, means that these systems may be better suited to higher- or medium-density developments. In this setting a cluster scale approach could be implemented where a single system serves a number of households.
- The innovative wastewater services approaches trialled at Kinglake West are likely to come at a financial premium when compared to servicing with a conventional gravity sewer system.
- UDT would be better suited to particular contexts where there is less likely to be dilution of yellow water, possibly using waterless urinals in commercial or public buildings. However, the financial feasibility of recovering costs by using yellow water for crop production was found to be limited by heterogeneity of yellow water, current costs of commercial fertiliser, and costs of collecting and transporting yellow water. Investigations into alternative configurations of using yellow water as a crop fertiliser supplement showed that it was not financially feasible, even if the yellow water was more concentrated.
- The project has demonstrated that it is possible to undertake applied research in the community with the co-operation and development of partnerships. This project developed strong partnerships among the involved parties, which included: YVW, households, local government, regulatory authorities, a turf farmer and research organisations (Mitchell *et al.*, 2011).
- In exploring innovative approaches to wastewater servicing there is a need for post-implementation assessment and monitoring, such as occurred in this project. This ensures that lessons can be used for refining the approach for future YVW projects, while also providing the broader urban water sector with important knowledge that can help facilitate increased adoption of more sustainable approaches.

CONCLUSION

This project has provided empirical evidence for the benefits and challenges associated with implementing source separation of wastewater to improve sustainability outcomes in servicing sewerage backlog areas. In particular, it has quantified the costs, operational issues and feasibility of concepts such as nutrient recovery from urine in a small community for agronomic production.

This paper was first presented at Ozwater'14 in Brisbane in May 2014.

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