Water Science & Technology—WST | 57.5 | 2008

Cross sectoral and scale-up impacts of greywater recycling technologies on catchment hydrological flows

N. Bertrand, B. Jefferson and P. Jeffrey

ABSTRACT

With the growth of urban areas and climate change, decisions need to be taken to improve water management. This paper reports an assessment of the impact of greywater recycling systems on catchment scale hydrological flows. A simulation model developed in InfoWorks CS (Wallingford Software Ltd) was used to evaluate how river flows, sewer flows, surface runoff and flooding events may be influenced when grey water recycling systems of different number and scale are implemented in a representative catchment. The simulations show the effectiveness of greywater recycling systems in reducing total wastewater volume and flood volume. However, no hydraulic impacts due to implementation of greywater was identified by the model.

Key words | greywater technologies, modelling, water demand management

N Bertrand
B Jefferson
P Jeffrey
Centre for Water Science,
Cranfield University,
Cranfield MK43 0AL,
UK
E-mail: *n.m.bertrand@cranfield.ac.uk*,
Tel.: +44 1234753336

INTRODUCTION

Urban water management faces two contemporary challenges. The first is supplying sufficient water to consumers and the second is alleviation of the risk of flooding. With the growth of urban areas and climate change, decisions need to be taken to supply sufficient water to consumers without damaging the environment.

The implementation of technologies to support greywater recycling can contribute to a reduction in demand for potable water and to the alleviation of sewer flooding. Greywater recycling refers to the reuse of wastewater from sources such as bath, shower and hand washing basins for applications such as flushing the toilet, landscape irrigation or washing cars (Friedler 2004). Toilet flushing represents approximately 30% of household water supply. Therefore, where water recycling is implemented for toilet flushing, up to 30% of water can be saved for non-potable applications (Diaper *et al* 2001). Over the last 10 years, greywater systems have started to be implemented for multiple-family buildings and their effectiveness in reducing both water potable demand and the risk of sewer floods have been proved (Nolde 2005). However, extensive implementation of such technologies is planned for new developments. The purpose of the project is to test how the hydrodynamics of a catchment might be altered by the scale-up and widespread use of greywater systems.

Consequently, this paper reports an assessment of the impact of greywater recycling systems on catchment scale hydrological flows. A simulation model developed in InfoWorks CS (Wallingford Software Ltd) was used to evaluate how river flows, sewer flows, surface runoff and flooding events may be influenced when grey water recycling systems of different number and scale are implemented in a representative catchment.

METHODS

Case study

The study was carried out in the Carrickmines catchment in Ireland, in an area to the south of Dublin. Currently, the area is mainly rural in character. However, significant urban development is planed for the coming years. Figure 1 shows the existing and expected urban area. The catchment

doi: 10.2166/wst.2008.176

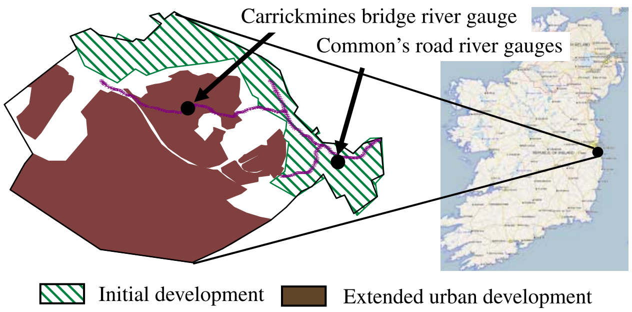

Figure 1 | The Carrickmines catchment urban development plans (adapted from Google 2007).

has a total area of 32 km^2 with a current impervious area of 25%. Once the expected urban development is implemented, the catchment will be densely populated. An increase of 82,950 inhabitants is expected and a total of 80% of the catchment surface will be impermeable. The sewers in Ireland are non-combined systems. Two river gauges monitor flows in the catchment. In recent years, floods have been observed at both locations. The maximum peak flow observed was on the 26th of May 1993, 14.3m^3/s at the Commons Road river gauge.

Our study evaluates how greywater scale-up will impact hydraulic and hydrological flows. Rainfall, catchment impervious area, runoff volumes, river, flows and the sewer network all

Need to be represented in the model. Figure 2 presents them within their respective platforms. The modelling platform selected for the study should then be able to model and combine hydrological and hydraulic platforms. InfoWorks CS (Wallingford Software Ltd) was selected as a suitable software for this study as it is able to model drainage and sewerage systems, wastewater treatment works, and urban drainage storm runoff and can also predict floods and assess the impacts of climate change.

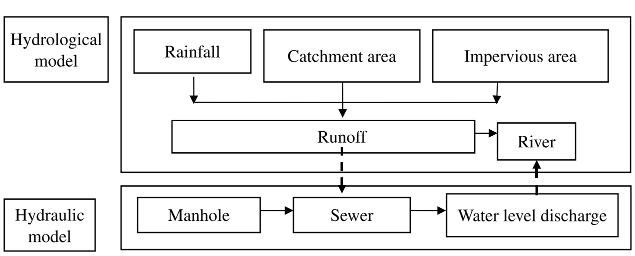

Figure 2 | Interactions between various components of the modelling approach. (adapted from Mark et al. 2004).

Data acquisition

A model of the Carrickmines catchment hydrology previously developed by HR Wallingford was provided as a starting point for model development. This base model had been developed to model urban drainage and the river flows has been calibrated. River flow data at the two river gauges were obtained from the Irish Environmental Protection Agency (EPA). Sewer base flow data were provided by the Dun Laoghaire County Council. Average, minimum, and maximum flow data from the inlet at the Shanganagh Disposal Works from the 1st January to the 31st January 2006 were made available. Moreover, the Dun Laoghaire County Council local development plan for the year the coming years was obtained. Observed rainfall data from the Carrickmines region were also obtained by HR Wallingford from the last 60 years.

Calibration

The Carrickmines' river was calibrated with the river gauge data provided by the EPA to evaluate the accuracy of the model. Figure 3 shows the calibration hydrograph at the Common's road river gauges in 1993 during an observed storm event. The calibration exercise showed it that for major storm events, the predicted flows were underestimated.

For the purpose of the study, a sewer network was designed using the software functions. The number of inhabitants and the location of buildings were known; however information about the location and size of the pipes were missing and guidance on appropriate sewer

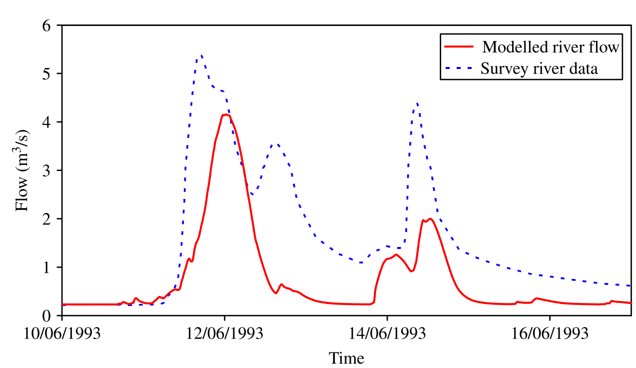

Figure 3 | Calibration hydrograph at the Common's road river gauges in 1993.

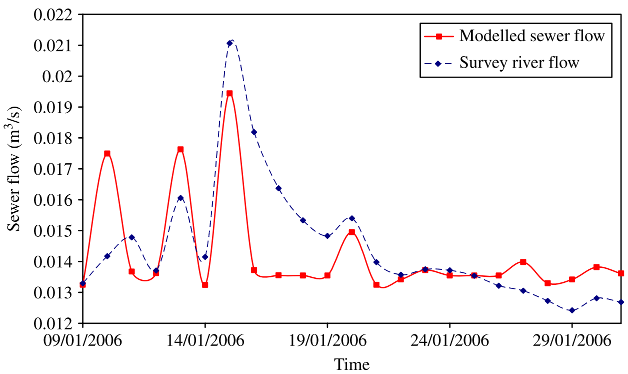

Figure 4 | Calibration hydrograph of the sewer network.

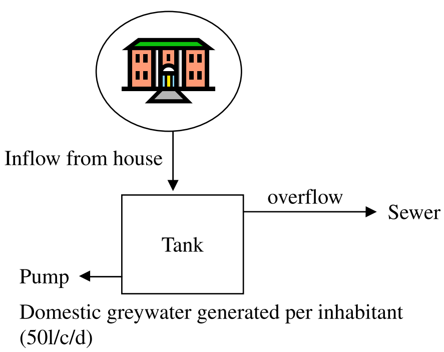

Figure 5 | A schematic of greywater use model.

configuration was consulted. The designed sewer network was calibrated; Figure 4 compares the modelled and surveyed total daily wastewater volume obtained for the calibrated period.

The sewer calibration hydrograph shows a small variation between the modelled and observed total daily sewer volume for the calibrated period. However, the model is overestimating sewer flows for small rainfall events and is over estimated flows for bigger storm events. This difference of flow observed is due to the lack of suitable data available to design and calibrate the sewer network.

Representation of greywater systems

For each greywater system represented within InfoWorks CS, a tank, a pump and an overflow back to the sewer was implemented. Figure 5 shows a typical greywater system. In order to represent the most realistic greywater recycling system, literature was consulted to determine a daily greywater generation profile and the tank size and the pumping time and rate (Gerba *et al.* 1995; Santala *et al.* 1998; Surendran & Wheatley 1998; Brewer *et al.* 2000; Friedler *et al.* 2004; Mars 2004). The following assumptions were also made: 50 l of greywater are generated per day per person, greywater is pumped back to the house twice a day between 7am to 8.30am and 20.30 to 22.00.

The three different sizes of greywater systems represented in the model are: household (one system per building), neighbourhood (five buildings connected to one system) and municipal scales (one system for the whole

Table 1 | Characteristics of the greywater systems when they were applied for each systems scales for the 2010 development

Development	Scheme scale	% of buildings connected	Number of systems	Number of total inhabitants connected	Number of inhabitants per system	Tank size (m^3)	Pump rate (m^3/s)
Existing development		–	–	–	–	–	–
Extended urban development	Household	20%	65	16,640	256	14.3	0.01
		50%	164	41,984	256	14.3	0.01
		80%	260	66,560	256	14.3	0.01
	Neighbourhood	20%	13	16,640	1,280	72	0.05
		50%	33	42,240	1,280	72	0.05
		80%	52	66,560	1,280	72	0.05
	Municipal	20%	1	16,640	16,640	1,000	0.73
		50%	1	41,984	41,984	2,520	1.64
		80%	1	66,560	66,560	4,000	2.92

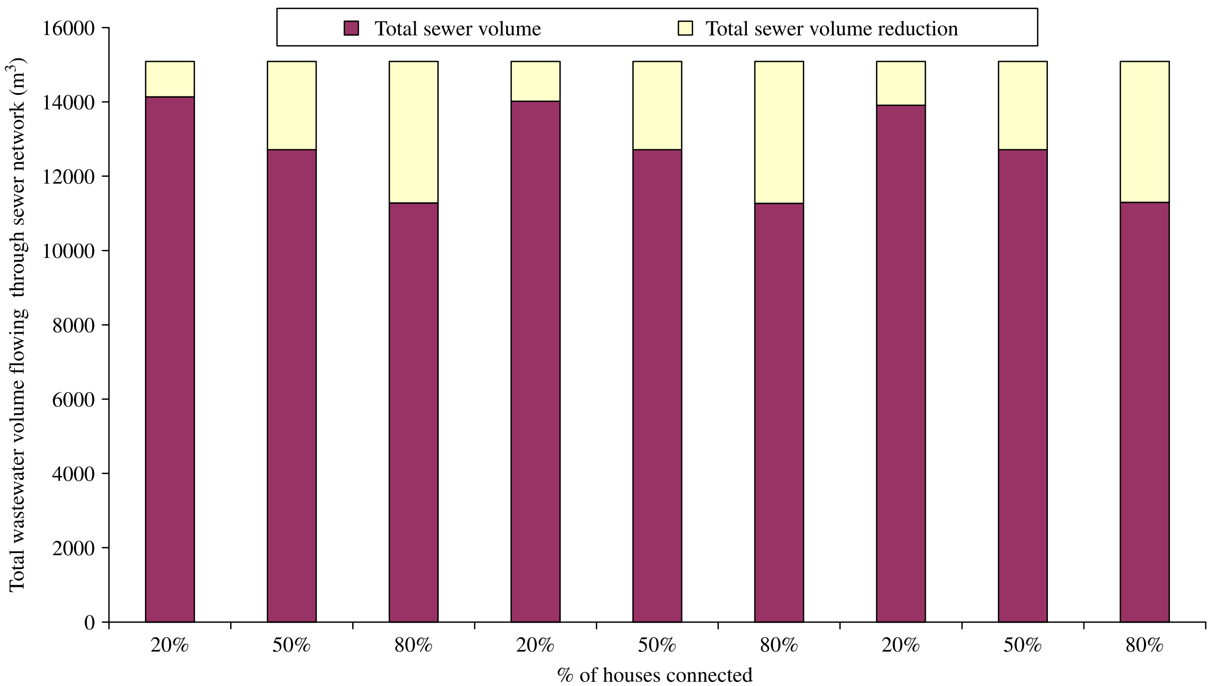

Figure 6 | Simulated reduction of total daily sewer flow for each scenario.

catchment). Tank sizes, greywater profile and pumps rates are proportionally scaled up according to the size of the system.

Scenarios

The simulations were designed to answer the following two research questions: (i) How might the scale up of greywater recycling reduce sewer flow? And (ii) How might the scale up of greywater recycling alter the catchment hydro-dynamic?

Two set of simulations were run. In the first set, the various greywater system parameters (size, number) are used to evaluate their impact on total sewer flow over ten scenarios. Table 1 reviews the ten simulations. For this first set of simulations, no rainfall events were simulated.

Table 2 | Influence of greywater recycling reducing sewer flows

Scheme scale	% of buildings connected	Total volume of wastewater (m^3)	% of wastewater volumes reduction in the expended area compares with basecase	% Total wastewater volume reduction for the whole catchment
	Basecase	15,091	–	–
Household	20%	14,131	6	5
	50%	12,716	16	12
	80%	11,283	25	18
Neighbourhood	20%	14,015	7	5
	50%	12,716	16	12
	80%	11,268	25	18
Municipal	20%	13,912	8	6
	50%	12,716	16	12
	80%	11,297	25	18

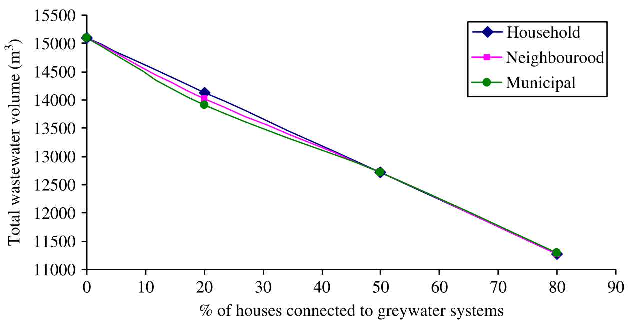

Figure 7 | Variation of total wastewater volume for each scenario.

For the second set of simulations, the same ten scenarios were used, but this time rainfall storm events were simulated. One, five, 10, 50 and 100 years return period event of a one hour duration were simulated to understand to what extent greywater implementation could reduce sewer flooding and how the hydro-dynamics of the catchment might be impacted.

RESULTS AND DISCUSSION

The simulation results for the first set of simulations are shown in Figure 6. The total volume of wastewater flowing through the development when no greywater recycling schemes are implemented is chosen as the comparative output parameter. The results show a decrease in total sewer volumetric flows for all each scenarios. The results show that the reduction of total sewer volume is proportional to the number of greywater systems present in the catchment.

Table 2 and Figure 7 illustrate how the different sizes of greywater system influence the reduction of total daily sewer flows. The results show that the total sewer reductions is not influenced by the size of the greywater recycling schemes. However when 20% of the buildings are connected a small difference of 2% is observed. The modelling activity has not shown any major hydraulic influence due to the size of the greywater systems modelled. The simulations also show that a reduction of 18% of the total daily sewer volume could be achieve if 80% of new buildings would be connected to a greywater systems.

The reduction in total wastewater volume showned above will reduce the risk of sewer flooding during storm events. The second set of simulations analysed the reduction of sewer flood volume within the Carrickmines catchment. Table 3 reviews the percentage of flood volume reduction for each scenario simulated for the respective storm events: one year return period during 60 minutes (M–60), five years (M5–60), ten years (M10–60), 50 years (M50–60) and 100 years (M100-60). The results show the effectiveness of greywater recycling to reduce sewer flooding. However, the reduction is limited. For the 10 year return period event, up to 57% of sewer flood volumes could be reduce whereas for the 50 year return period event only 16% could be reduced. With global warming, the chance of a 100 year return

Table 3 | Percentage reduction of sewer flood volume

Scheme scale	% of buildings connected	% sewer flood volume reduction				
		M1–60	M5–60	M10–60	M50–60	M100–60
Household	20%	No flood	90	27	6	4
	50%	No flood	No flood	45	12	7
	80%	No flood	No flood	56	16	9
Neighbourhood	20%	No flood	95	29	7	4
	50%	No flood	No flood	45	12	7
	80%	No flood	No flood	57	16	9
Municipal	20%	No flood	96	30	7	4
	50%	No flood	No flood	45	12	7
	80%	No flood	No flood	57	16	9

period event occuring is increasing; therefore the results obtained with the implementation of greywater to reduce sewer volume may not be sufficient to mange sewer flooding for events bigger than the 50 year return periods events.

SIMULATION PLATFORM

The influence of greywater system implementation on urban hydrology was analysed using the second set of simulations. The results show no variation in river flows and river and drainage flood volumes. It can be conclude that greywater systems do not significantly influence the urban hydrology within the catchment. As a result, where greywater is to be implemented, flood control technology will also be needed to enhance storm water drainage to manage floods.

CONCLUSION

(1) Greywater recycling results in a reduction of sewer volumes; thereby positively influencing sewer flood risk especially in urban area where the sewer network is combined. The reduction in sewer volumes is proportional to the number of greywater systems implemented in the catchment and the quantity of greywater generated. For a proportional size of tank, the modelling activity has shown no significant difference in the quantity of sewer volume reduction. No hydraulic impacts have been identified when greywater systems are scaled up within the Carrickmines catchment.

(2) Greywater recycling has the capacity to significantly reduce sewer flooding for storm events of up to 5 years return period. A reduction of 57% of the total sewer flood volume was observed for 10 years return period when 50 litres of greywater is recycled per habitant. Therefore, by decreasing the amount of water discharge in sewer greywater reduce the risk of sewer flood during storm events. However, the modelling activity has shown the limit of reducing sewer floods.

(3) Greywater implementation does not impact diurnal or seasonal hydrological flows within the catchment. Therefore, where floods occurred due to high urbanisation implementation of greywater will not be sufficient to manage storm water. Where greywater recycling is to be implemented, urban drainage technology will also have to be present within the catchment to enhance urban drainage in order to control urban flooding.

ACKNOWLEDGEMENTS

EPSRC granted financial support for the research project and the WaND project for providing data.

REFERENCES

Brewer, B., Brown, R. & Stanfield, G. 2000 Rainwater and grey water in buildings: project report en case studies.

Diaper, C., Jefferson, B., Parsons, S. A. & Judd, S. J. 2001 Water-recycling technologies in the UK. *J. Charter. Inst. Water Environ. Manage.* **15**(4), 282–286.

Friedler, E. 2004 Quality of individual domestic grey water streams and its implication for on-site treatment and reuse possibilities. *Environ. Technol.* **25**(9), 997–1008.

Friedler, E., Kovalio, R. & Galil, N. I. 2004 Proceedings of the 1st International Conference on Onsite Wastewater Treatment & Recycling. Fremantle, Western Australia. February, 11–13, 2004.

Gerba, C. P., Staub, T. M, Rose, J. B., Karpiscak, M. M., Foster, K. E. & Brittain, R. G. 1995 Water quality study of greywater treatment systems. Water Resources Bulletin (American Water Resources Association) vol. 31, no 1, pp. 109–116.

Google. 2007 Map of Ireland. Internet: http://images.google.fr/imgres?imgurl = http://www.itraveluk.co.uk/images/maps/ireland-map.gif&imgrefurl (Accessed: June 2007).

Mark, O., Weesakul, S., Apirumanekul, C., Aroonnet, S. B. & Djordjevic, S. 2004 Potential and limitations of 1D modelling of urban flooding. *J. Hydrol.* **299**, 284–299.

Mars, M. 2004 Proceedings of the 1st International Conference on Onsite Wastewater Treatment & Recycling. Fremantle, Western Australia. February, 11–13, 2004.

Nolde, E. 2005 Greywater recycling systems in Germany – results, experiences and guidelines. *Water Sci. Technol.* **51**(10), 203–210.

Santala, E., Uotila, J., Zaitsev, G., Alasiurua, R., Tikka, R., Tengvall, J. 1998 Microbiological greywater treatment and recycling in an apartment building. Proceedings of the Advanced Wastewater Treatment, Recycling and Reuse conference, Milano, Italy. September, 14–16, 1998.

Surendran, S. & Wheatley, A. D. 1998 Grey water reclamination for non-potable reuse. *J. CIWEM* **12**, 406–413.