ABSTRACT

Water is an essential and scarce resource that must be protected. Greywater reuse (GWR) presents a promising option to the growing pressure on fresh water resources. In spite of government and public interest and opportunities for water conservation, the potential for GWR has not been fully exploited in many countries, including South Africa. The limiting factors hindering GWR have been the potential risks of failure due to several factors including negative perceptions, selecting inappropriate GWR technology, economic non-viability, and hazards to beneficiaries' health due to cross-connection between a greywater pipe and a potable water pipe. If holistically and adequately addressed, these risks can be mitigated.

This thesis develops and implements integrated risk management in the implementation of dual grey and potable water reticulation systems in South Africa. This aim was achieved by undertaking research targeted at addressing five objectives i.e. (i) to monitor the evolving perceptions of users towards GWR for toilet flushing in high-density urban buildings before and after GWR implementation; (ii) to measure toilet flushing water consumption in high density urban buildings and develop a model for estimating historical toilet flushing demand; (iii) to develop and apply a robust framework for evaluating available package plants for GWR for toilet flushing; (iv) to investigate the economic viability of the implemented pilot GWR systems; and (v) to model and simulate the transport of contaminants (specifically nitrate and phosphorus) within a dual grey and potable water reticulation system. This last objective was carried out to investigate the degree of human exposure to these contaminants at various times of the day, due to varying contaminant quantities, and at different injection points.

A detailed literature survey was carried out and this provided extensive knowledge, and experience of water resources in South Africa, motivations for GWR, greywater characteristics, success and controversial GWR case studies, and lessons learnt. In addition, the literature survey focused on identifying, assessing, and quantifying potential health risks associated with the implementation of GWR for toilet flushing. The literature survey thus assisted in the development of an integrated risk management framework which was employed in this study based on various frameworks published in the literature.

The original contributions of this thesis were focused on certain technical and economic, social, and environmental risk management measures investigated, developed and/or implemented. The social measures implemented to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites were the evaluation of perception surveys carried out on potential and actual beneficiaries of GWR for toilet flushing, public awareness and involvement, and an analysis of the attributes that are important to beneficiaries regarding GWR and understanding the willingness of beneficiaries to pay for some of these attributes. The above measures involved designing, administering, collecting and coding the questionnaires used to determine perceptions; regular community engagement; a review of the analytical methods available to analyse perceptions and selection of a suitable method; and modelling the factors that influence respondents' attitudes to some attributes of greywater using conjoint analysis. Levels of respondents' trust and confidence in the GWR implementing team, and the importance attributed to a pleasant smell of the greywater in comparison to colour and tariff emerged as the critical areas requiring attention.

The technical measures implemented to manage and therefore mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites includedthe development of a framework for evaluating locally available GWR systems using sustainability criteria and thus mitigating the risks associated with choosing inappropriate systems for a specific reuse application; measuring and modelling toilet flushing demand; and the analysis of the economical viability of the pilot GWR systems using cost benefit analyses. The framework developed was valuable in holistically evaluating locally available GWR technologies, although it became more evident that there were no simple formulas for selecting a technology due to the trade-offs that had to be made between the three key evaluation criteria i.e. technical, economics and public health. The model developed for estimating toilet flushing demand within a non-residential (specifically academic) building was based on 4 factors (i.e. bulk water demand, rainfall, maximum and minimum temperature) and was proven to be reliable. Economically, the cheapest of the locally available GWR systems which were implemented at WITS and UJ were not viable with payback periods at WITS and UJ computed at 18 yrs and longer than 20 yrs respectively.

The environmental measure implemented to mitigate the risks of failure associated with the implementation of GWR for toilet flushing at the pilot sites involved the modelling of greywater contaminant transport within a residential (UJ) potable water network due to accidental or deliberate ingress. Some key results that emerged from the modelling and simulation exercise were (i) the degree of human exposure to the contaminants was directly dependent on the demand occurring adjacent to the period of ingress; (ii) based on the typical quantities of nitrate and phosphorus in shower and bath greywater which has been sieved and disinfected with chlorine, there is an insignificant immediate risk to human health from ingestion of these contaminants as specified in the South African National Standards for Drinking Water; (iii) the risk of contaminant ingestion is directly proportional to the distance from the point of injection; and (iv) the movement of contaminants is affected by the demand pattern of the users and thus, if a contaminant is injected prior to or during a peak period, the contaminant is certain to reach all the water use fixtures and at a shorter space of time i.e. in minutes or seconds depending on the size of the network. Despite the low risks to human health that emerged from the contaminant analysis, it is recommended in the thesis that standard precautions be observed in the use of the greywater toilets and in the maintenance of the GWR system. For example, the use of more natural soap products that contain less chemical constituents, hand washing after toilet use, dropping the greywater toilet seat cover before flushing, and proper labelling of the greywater system.

In conclusion therefore, the planning and sustainability of GWR initiatives in South Africa will immensely benefit from addressing the above measures which have been shown to mitigate the risks of failure associated with GWR.