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Sustainability investigation tools for water management in new developments

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ABSTRACT

This paper provides an overview of some of the tools being developed, in a UK based multi-disciplinary project on water cycle management for new developments (WaND), to investigate the performance of a range of water management strategies in sustainability context. Models described include tools for forecasting the impact of water demand management measures and new developments on water demand, simulating the environmental, economic and system performance of greywater recycling strategies, evaluating the preliminary design and performance of stormwater drainage systems and assessing flood risk in new developments. In total, 12 tools are introduced in this paper. For each tool, its development strategy (architecture), application and key results are discussed briefly.

Key words: flood risk assessment, greywater recycling, storm water drainage sustainability evaluation, water demand forecasting, water management.

1. INTRODUCTION

Economic migration to the southeast of England, in particular, together with changes in family structure and an ageing population, are putting immense pressure on the housing stock and existing infrastructure. To meet this increasing demand, the UK government is implementing a substantial and extended development process over the next ten years with the development of so-called Sustainable Communities. These new developments will potentially have enormous ‘footprints’, and have

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implications for existing resources (including water), unless they are planned designed and managed in a sustainable manner.

A 4-year multi-disciplinary research project management focussed on Water Cycle Management for New Developments (WaND)[2] has been carried out to explore the implications and needs of new developments for improved sustainability. The project consists of 13 sub-projects and is developing about 20 tools to investigate the planning, design, feasibility and implications of water management strategies. The purpose of this paper is to provide a brief overview of 12 WaND tools developed to:

- forecast water demand;
- investigate greywater recycling systems;
- manage stormwater; and
- assess flood risk and plan mitigation measures in new developments.

The remaining 8 tools focused on strategic decision making are presented in Memon et al. (submitted).

2 TOOLS FOR WATER DEMAND FORECASTING

Whatever management measures are put into place, the demand for potable water is bound to increase as new developments are constructed and greater numbers of people move into particular areas. Unless carefully planned, this will put significant pressure on already overstretched infrastructure and water resource provision, particularly in southeast England. Therefore, it is important to be able to quantify demand projections and capture the influence of new developments with due consideration to site specific resource constraints and social trends and implementation of water demand management strategies. To do this, WaND has produced two tools: MicroWater and MacroWater. These are briefly described as below.

2.1 MicroWater

MicroWater produces domestic water demand forecasts and captures the influence of several variables including:

- Micro-components (water use points) attributes (including water saving devices)
- Social, technological and regulatory induced changes
- Household occupancy
- Water metering
- Greywater recycling
- Climate change

[2] www.wand.uk.net

- Population growth

The tool has developed a baseline forecast using 2001 census data, OFWAT metering data and domestic consumption monitors record to predict demand for the UK Government Office Regions. The MicroWater modelling method is scaleable and can be applied to long term demand forecasting from street to national level, so long as appropriate demographic data is available. This is an Excel based tool designed to be interactive and user friendly in terms of its layout, functionality and visualisation of results, and is intended to be useful for industry planning/analysis and educational use. Further details on the characteristics of employed data and tool architecture can be found in Parsons et al. (2005).

2.2 MacroWater

MacroWater is developed using a top-down approach to forecast water demand for each of the local authorities and water company areas in England and Wales. It predicts the net impact of housebuilding and water efficiency levels for a range of scenarios and produces corresponding maps showing demand variability within an area under consideration. The tool development strategy required an extensive synthesis of domestic water consumption records obtained from water companies operating in England and Wales and associated attribute data (e.g. household classification). Forecasts are produced to the year 2031 based on 5-year time steps. The tool has been applied on a number of case study sites including Thames Gateway and several UK Office Regions.

MACROWater is a web application that connects to a PostgreSQL database with GIS extensions. It produces water demand forecasts as dynamic spreadsheets or in a map form (using UMN MapServer). For maintainability and security, it uses a 3-tier architecture using Java components, such as Spring, POI and Hibernate. Microsoft Excel and Access are used for data preparation and population forecasting; ESRI ArcGIS is employed for preparing the case studies' boundaries and geographic conversion tables. For responsiveness, much of the forecasting is performed using SQL operations. The data synthesis and model building involved application of several techniques including additive accounting, iterative proportional fitting and fuzzy matching (for missing company data). Further details on data synthesis and tool development strategy and application can be found in Parsons et al. (2007).

3. GREYWATER RECYCLING TOOLS

Grey water recycling has been used internationally in water stressed areas, but so far has not found widespread uptake in the UK. In principle, it helps in the preservation of high quality fresh water supplies and potentially reduces the pollutant load to the environment. Greywater is defined as water that is slightly contaminated by human activities (e.g. water from personal washing, showers, baths and possibly washing machines) which may possibly be reused after suitable treatment. Treated grey water, in a household context, is used for toilet flushing and/or garden watering (Liu et al, 2007). A typical system consists of three components:

- A tank to store raw greywater
- A pump/treatment unit
- An overhead tank to store treated greywater (green water) prior to supply to the toilet.

Practical experience of single household systems has been mixed, and it is argued this is partly due to poor system design. The WaND project has developed a number tools to investigate aspects related to the environmental, economic and design performance of greywater systems to increase confidence in system performance and specify the appropriate scale of provision. These tools are briefly described below:

3.1 Storage tank sizing tool

This model is able to clearly represent the main elements of any recycling system (inputs, outputs, tank sizes and treatment capacity) to allow determination of storage tanks volumes to be calculated in a more rational and realistic way. It also provides insights into the relationship between performance and system configuration. Figure 1 is an example model output showing the relationship between the size of greywater and green water tank and theoretical water saving efficiency (WSE)).

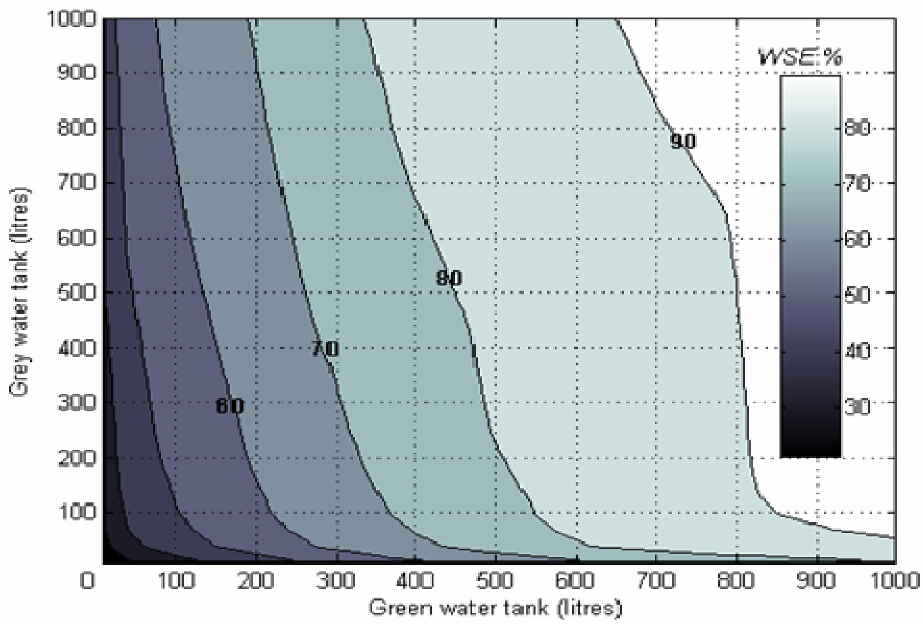

Figure 1 Relationship of water saving efficiency and storage tank volumes

The main model has been developed using an object-based approach implemented in MATLAB. The model is linked with a purpose built user interface in Excel via an ExceLink module. Further details on the model architecture and tool implementation is available in Liu et al (2007).

The model can be used to assess system performance from both a volumetric and water quality point of view. Results from the volumetric analysis indicate that a higher water saving efficiency can be achieved for a system with larger green water tank sizes, but that grey water tank volume is relatively insignificant above a certain minimum. The quality-based analysis highlights that although larger volume tanks produce higher water saving efficiencies, smaller volume tanks (offering short hydraulic retention time) are needed to secure good water quality.

3.2 LCA tools

The life cycle analysis (LCA) tool is aimed at investigating the environmental impact of greywater treatment technologies investigated in WaND. Two conventional (reed beds and membrane bioreactor (MBR)) and two innovative (GROW and membrane chemical reactor (MCR)) technologies have been considered. Inventories for the use and construction phase, for each technology, were prepared and LCA outputs generated for a range of development scales (from 50 to 2000 households) using conventional LCA protocols. The LCA outputs for each technology were processed using an adaptive neuro-fuzzy inference system in MATLAB to develop a set of technology specific generic tools. These tools have the ability to capture the influence of development scale, energy use and material consumption (in technology construction and operation) on key environmental impact indicators (e.g. abiotic depletion, global warming, human toxicity, acidification and eutrophication). Simulation results indicate that per capita environmental impact is inversely proportional to the development scale and energy intensive technologies have high environmental impact. Further details on the introduction of the investigated technologies, the LCA procedure, the tool development strategy and application can be found in Memon et al. (in press). Figure 2 is an example graphical representation of the contribution of stainless steel and PVC (used in the membrane based treatment technologies) towards environmental impact indicators (global warming and human toxicity).

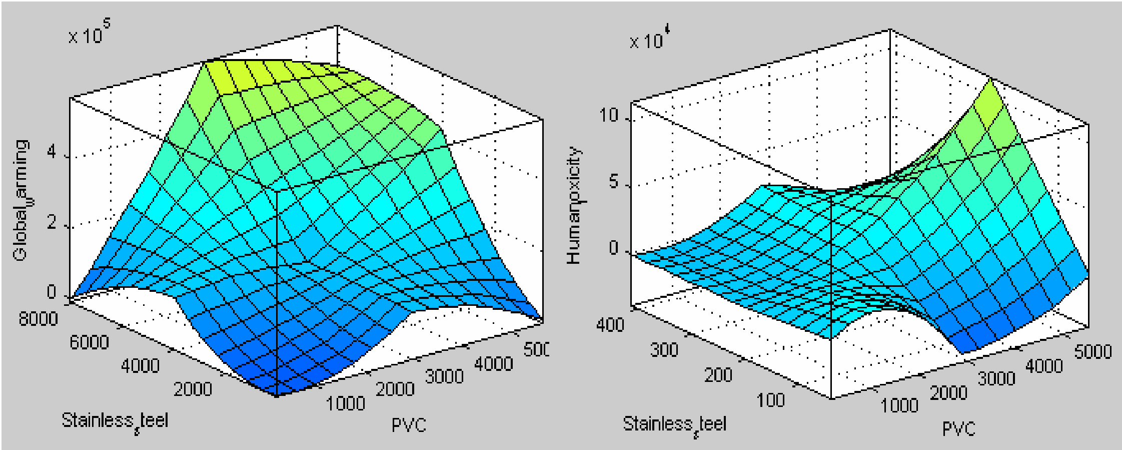

Figure 2 Example output from LCA tool showing environment impact of materials used in membrane based technologies.

3.3 Economic assessment tool

This tool is aimed at quantifying the whole life cost and performing cost-benefit analysis of greywater recycling systems using the development scale, technology attributes and users' water consumption patterns as the key influencing variables. The tool can be used to investigate the influence of:

- System design life
- Water saving appliances
- Water pricing strategies
- System maintenance regime
- Climate change
- System efficiency

The tool consists of four integrated modules:

Input module: The input module provides a mechanism to select parameter values necessary for defining the scale of greywater recycling system (i.e. single household, medium or large scale) and efficiency of the system. The scale of system is assumed to be dependent on the average number of residents and days when greywater is produced and recycled.

Water flow module: The simulation results from this module provide input for cost calculations and quantify water saving potential. The module has two components: greywater generation and consumption. The greywater generation and consumption quantification has been carried out using micro-components associated attributes (ownership and frequency of use for each appliance and nominal water consumed per use by each appliance contributing to greywater).

Cost quantification module: This module calculates the net cost of a greywater recycling system by taking into account the capital cost, regular and unplanned maintenance and operation costs and savings resulting from greywater reuse.

WLC assessment module: This module computes the whole life cost (WLC) of a grey water recycling system as a function of total capital cost and the net present (NPV) of running (O & M) cost and decommissioning cost incurred at the end of the design life of the recycling system.

The tool was applied using cost data from two case studies. The results indicate that the large scale greywater recycling systems are financially viable. Additionally, low flush toilets have a negative impact on cost-benefit ratio, since they reduce water use potential of treated greywater. Further details on the tool development strategy and its implementation for quantifying the whole life cost for two case studies can be found in Memon et al. (2005).

4 STORMWATER MANAGEMENT TOOLS

Stormwater management is an important component of urban water cycle. New developments provide opportunities to deploy innovative stormwater management solutions, which can be planned in at an early stage. Properly designed solutions have the potential to deliver acceptable performance and enhance sustainability requirements. To address this, a number of tools have been developed to investigate issues surrounding the design of stormwater management options and assess their sustainability. These can be classified into two groups:

- Tools for preliminary drainage design (drainage guidance flow chart, initial storage assessment tool, joint probability assessment tool, infiltration design tool)
- Tools for the evaluation of sustainability of detailed drainage design (Environmental assessment tools for hydraulic performance and water quality evaluation)

These are briefly described as below

4.1 Drainage guidance flow chart

This tool is intended for developers, consultants or planners interested in exploring aspects associated with the preliminary design of a stormwater drainage system. The tool requires the user to identify the site's location and respond to a series of questions that act as a selection process for producing a bespoke report providing guidance on the selection of drainage components for a new development. This report provides guidance regarding:

- Whether or not to use infiltration
- What level of stormwater treatment is needed
- What should be the discharge limit for the site drainage
- What type of stormwater drainage system should be used (i.e. suitable types of sustainable drainage systems (SuDS), etc.

4.2 Initial storage assessment tool

This tool is an automated procedure for estimating storage volumes for stormwater management at the initial outline design stage. It provides an estimate of attenuation storage, interception storage, long-term storage and treatment storage. An explanation of each form of storage and guidance of parameter input values is provided from the database built within the tool. Most parameter values are automated allowing the tool to be used by planners and developers, as well as consultants. The tool will be broadly similar to the Irish SuDS Stormwater Storage Assessment Tool[3].

4.3 Joint probablity assessment tool

This is an Excel based tool designed to assist water professionals to quantify the effect of the dependency relationship between river flow and site rainfall. SuDS are often based on storage; the critical duration events for a site are usually in the region of 12 to 24 hours. Storage components such as ponds are usually located at the lowest point of a site and this can have implications with regards to discharges to receiving waters. This tool allows joint probabilities to be determined to analyse the effect of high river levels on the performance of the drainage system. Guidance is provided on the process of deriving dependency functions and typical dependency values are suggested.

4.4 Infiltration assessment tool

This tool enables the sizing of infiltration soakaways or infiltration trenches for any location in the UK. This is intended for use by water professionals involved with the design, construction and maintenance of infiltration drainage. The tool is based on the earlier work carried out by Bettess (1996).

4.5 Environmental assessment tool – hydraulic performance

This is aimed at providing a measure of the sustainability of the performance of the stormwater drainage system serving an urban area in the UK. The performance indicators are based on a comparison between pre and post development response of a site to rainfall. The principle being applied is that post-development should replicate as closely as possible the pre-development state. Five measures are used based on hydraulic model outputs from time series rainfall:

[3] (http://geo.hrwallingford.co.uk:8080/wmc/savedapps/suds)

- Peak flow rate for extreme events
- Peak flow rate for frequent events
- Volume of runoff for extreme events
- Volume of runoff for frequent events
- Annual volume of infiltration

Peak flow rates and runoff volumes are determined from individual events from time series data. Annual volume of infiltration is determined from a continuous series. Both the pre-development and post-development states are modelled using separate hydraulic modelling software. The tool has been developed using techniques available in Excel and Visual Basic and targeted users include water professionals interested in hydraulic modelling.

4.6 Environmental assessment tool – water quality

This tool is aimed at assessing surface water runoff treatment effectiveness provided by a stormwater drainage system. A performance indicator is used to assess the level of treatment provided. The performance indicator is a function of site area, percentage of impervious area, land use types, drainage outfall discharging boundary and the drainage treatment components.

This tool is not based on comparing the runoff water quality with greenfield conditions, nor does it attempt to compute pollutant concentrations. It assumes that runoff is only contaminated from man-made surfaces. Green areas are excluded. Infiltration runoff is also not evaluated.

This is an Excel/Visual Basic tool, designed for use by consultants undertaking the detailed design. A selection of the above mentioned stormwater management tools is currently being explored for integration with professional urban water management software packages.

5 TOOLS FOR FLOOD RISK ASSESSMENT

New developments are likely to increase imperviousness and enhance risk for flooding in urban environment. Urban flooding is caused by insufficient hydraulic capacity of the sewer system (“minor system”) and manifests itself as exceedance flows travelling on the surface during extreme rainfall events. Surface flows are conveyed in the “major system” (conventionally unplanned) consisting of existing roads, natural pathways and local depressions on the surface. The “background” flood risk in new developments can be estimated using planned land-use and terrain data to locate flood pathways and potentially vulnerable areas. Innovative GIS-based modules for analysing surface flooding were developed by Boonya-aroonnet et al. (2007) have been implemented to investigate flooding in and by new developments.

The flood risk assessment tool developed for WaND estimates the overall drainage capacity (major and minor systems and its interface) of the planned urban development areas. It aims to identify potentially vulnerable areas and suggest the improvements (for example ground work, flow paths alteration) to reduce the flood risk at minimum cost before development takes place. Schematic usage of the tools is shown in Figure 3. The tool has been implemented using a synthetic case study with a view to demonstrate its application, compare pre and post development flooding state and visualise the impact of development layout alterations on flood risk mitigation.

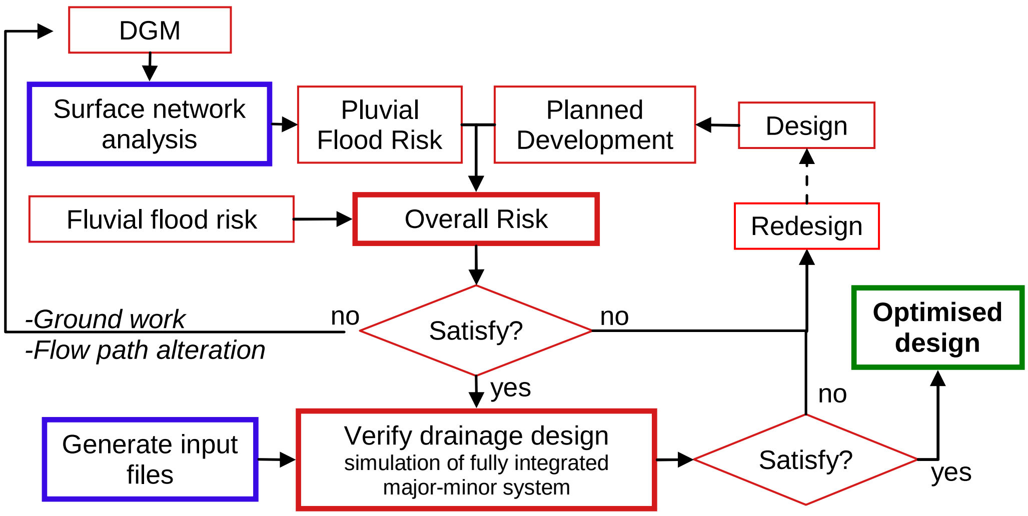

Figure 3 The procedure to reduce the overall flood risk for a planned urban development

The risk assessment tool is envisaged to help planners and designers to:

- identify the flood vulnerable locations and evaluate the city layout against risks from flooding,
- plan the storm sewer network and SuDS,
- decide on necessary groundwork for minimising risk of flooding, and
- landscape the urban area with water features such as retention ponds to serve both flood protection and recreational purposes.

6 CONCLUSIONS

The sustainability debate has moved on from definitions to solutions. However, a thorough investigation is required before rolling out any innovative water management options in new developments. This paper has introduced a number of tools developed to investigate sustainability aspects related to water management options for new developments. Tools for forecasting water demand, analysing greywater recycling systems, stormwater management and flood risk assessment have been briefly discussed. The purpose of this paper was to inform the reader about the type of tools available for further exploration and implementation. The tools presented here have currently been applied to a number of case study sites with a view to further refine their architecture and enhance user friendliness.

7 ACKNOWLEDGEMENTS

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