MODELLING URBAN DRAINAGE BMPS WITH HYDROWORKSTM / INFOWORKS TM

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Abstract

The term 'Urban Drainage Best Management Practices (BMPs)' refers to a range of physical storm-water management devices, such as infiltration structures or detention ponds, which are aimed at reducing, or attenuating, peak storm-water runoff conveyed from the urban catchment to the sewer system. This paper outlines how the hydraulic performance associated with such devices may be modelled using the HydroWorks, or InfoWorks, software packages. The paper focuses on the modelling of rainwater collectors from roof drainage and introduces an infiltration module appropriate for semi permeable pavements.

Keywords

Sustainable Urban Drainage Systems (SUDS), Urban Drainage Best Management Practices (BMP), HydroWorks, InfoWorks, Roof-water collection

introduction

In most UK cities the surface runoff generated on roofs and paved areas is generally directed into a combined sewerage system. During periods of high rainfall such systems can overflow into local rivers causing unacceptable aquatic pollution events. The conventional solution to this problem involves the construction of in-sewer storage tanks to detain these excess flows. However, such solutions can be costly and difficult to maintain. Recent years have seen the emergence of alternative approaches to storm-water management. These have included a variety of systems such as detention basins, filter (French) drains, infiltration trenches, porous pavements, retention ponds, swales and wetlands (CIRIA, 1992). Such technologies are often collectively referred to as urban drainage ‘Best Management Practices’ (BMPs), or ‘Sustainable Urban Drainage Systems’ (SUDS). These methodologies may be used to address both ecological (e.g. water quality) problems and hydraulic issues (e.g. flooding and overloaded sewer systems).

Urban drainage BMPs may be categorised into two distinct groupings: i.) ‘Structural’ and ii.) ‘Non-structural’. The term ‘Structural BMP’ refers to a broad range of physical stormwater management devices aimed at reducing, or attenuating, peak storm runoff conveyed from the catchment to the sewer system. These include infiltration devices and detention/retention structures. The term ‘Non-structural BMP’ describes an array of institutional, remedial and social issues, which also relate to the prevention of urban water pollution. Examples of ‘non-structural BMPs’ include improved street-sweeping and public education on the disposal of oils.

In recent years, a number of models (e.g. R-Win, SMUSI and SWIFT) have been specifically developed for representing the hydraulic behaviour of an array of BMP techniques. These models have generally been based upon simplistic modelling approaches, such as mass-balance flow analysis conducted over large, aggregated, time steps (Ashley et al., 1998; Ristenpart, 1998). This paper however, explores the potential for modelling BMP techniques with HydroWorksTM and InfoWorks TM, both of which are ‘deterministic’ urban drainage analysis models. HydroWorks is well established within the UK water sector, and consequently has a large pool of experienced users and available model catchment data. InfoWorks is a more recent product, which utilises the based upon the earlier HydroWorks’ simulation engine, butand incorporatinges an improved data handling facility. The current versions of HydroWorks and InfoWorks, like most of their competitors, contain no direct procedures for representing the behaviour of BMP-type technologies.

This paper presents preliminary work towards modelling BMP techniques within HydroWorks and InfoWorks. Section 2 contains a brief review of the existing HydroWorks model (simulation engine). Section 3 outlines a preliminary modelling exercise conducted at the University of Sheffield, which investigated alternative procedures for representing ‘localised roof-water detention’ schemes using HydroWorks. Section 4 briefly presents a new infiltration module, currently being developed for InfoWorks by Wallingford Software, which is likely to improve the modellling of ‘infiltration-based’ BMP techniques. Section 5 highlights the scope for future work.

HYDROWORKS

Introduction

The HydroWorks urban drainage software package can simulate both hydraulic and water quality aspects of the urban water cycle. The model comprises three interrelated modules, which individually represent the ‘Rainfall’, ‘Runoff’ and ‘Sewer System’ processes inherent within the urban drainage catchment (Figure 1).

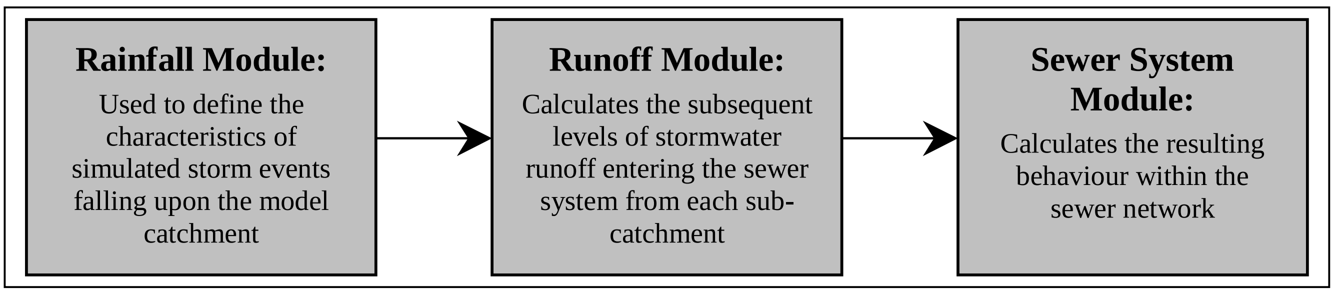

Figure 1: Simplistic flow-diagram of the HydroWorks process modules used to represent the Urban Water Cycle

The ‘Rainfall’ and ‘Runoff’ process modules are of particular relevance to this study, since these determine how much of the rainfall falling on the catchment is considered to become runoff and how quickly this then enters the drainage system. The HydroWorks’ ‘Runoff’ process module comprises three distinct sub-modules: i.) Initial losses module, ii.) Runoff Volume (net rainfall) module and iii.) Runoff Routing module (see Figure 2).

HydroWorks assumes that a catchment is divided into a series of sub-catchments. Figure 2 shows the rainfall input falling upon one such sub-catchment as being divided between 3 surface types. HydroWorks uses separate surface types to define distinct categories of surface, such as roads, roofs and pervious areas. Typically, three surface types are adequate to describe the different areas of a sub-catchment. However, up to twelve surface types may be defined for any given sub-catchment.

HydroWorks contains a number of different runoff modes. Within the UK, HydroWorks is most commonly operated in its default mode, which adopts the Wallingford Procedure set of runoff equations (National Water Council, 1981). However, the software also contains a number of non-default settings that are intended for unusual applications.

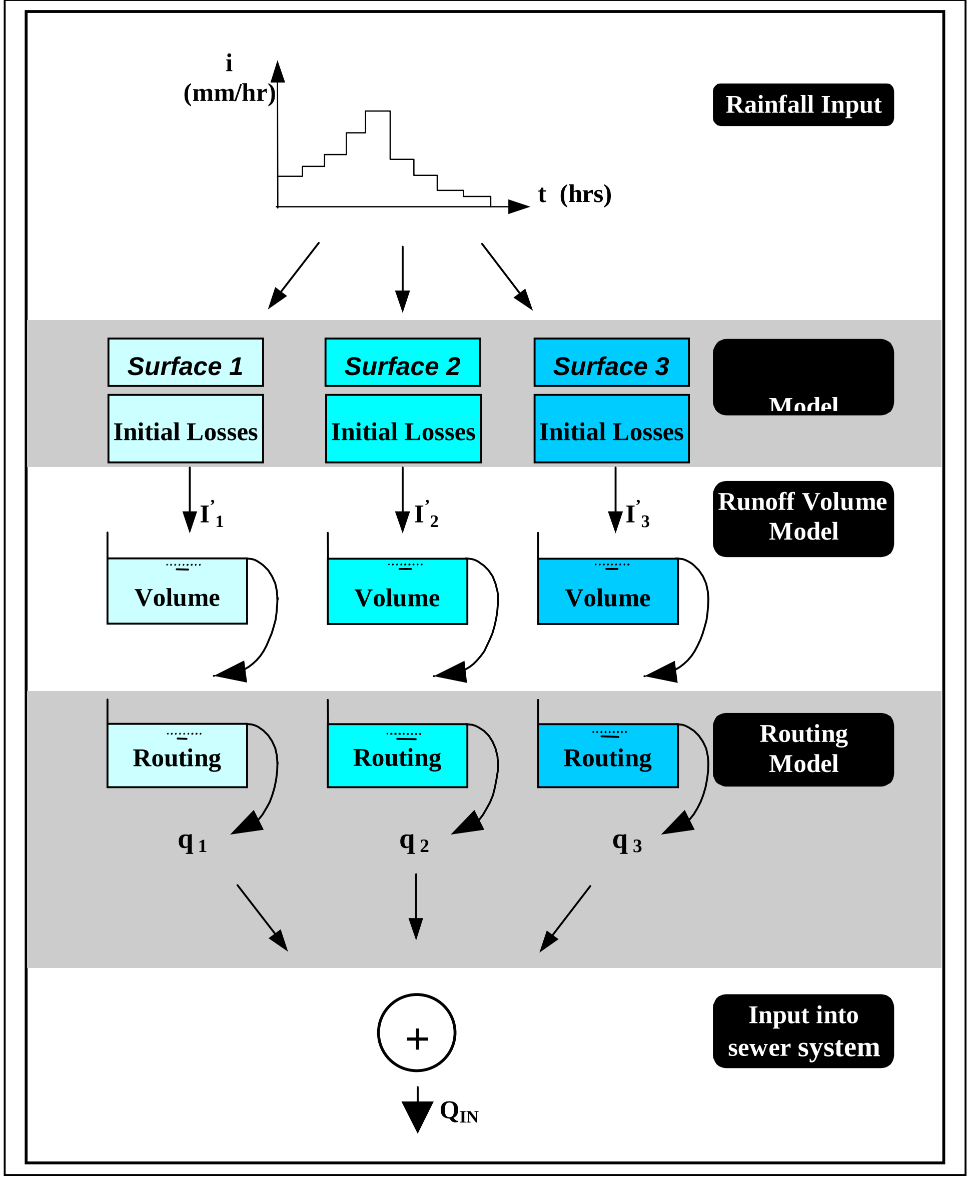

Figure 2: Simplistic Flow-diagram representing the 3 distinct sub-modules of HydroWorks runoff module

Initial losses model

The initial part of a storm event is generally assumed to cause no runoff because it is lost in wetting the ground surface and in depression storage (i.e. forming puddles). The quantity of rainfall required to just cause overland flow may be described as 'initial losses'. These losses are generally considered to depend upon surface type and slope. HydroWorks (Ver.4.0NT) contains 3 initial losses models:

Model Name	Description
Absolute model	This uses a direct value equal to depression storage depth
Slope model	The assumed value of depression storage is related to ground slope(s) by the expression, $D = k / \sqrt{s}$ **(default model)**
SCS model	The assumed value is a proportion of the retained storage depth

Table 1 : HydroWorks' Initial Losses Models

Runoff Volume (net rainfall) models

Runoff volume models are used to determine how much of the rainfall runs off the sub-catchment into the drainage system. These models are generally used to account for continuing losses, such as those associated with infiltration or interception (Saul, 1997).

Model Name	Description	Formula*/Basic Process
Fixed Percentage Runoff	Defines a fixed percentage of rainfall that is considered to runoff from a given surface	PR = c
Wallingford Procedure (Fixed) PR	The standard UK urban runoff model **(default model)**	PR = 0.829PIMP +25.0SOIL +0.078UCWI –20.7
New UK (Variable) PR	Represents the changing condition of pervious surfaces due to rainfall throughout the simulation	PR = IF *PIMP+ (100-IF*PIMP) *(NAPI / PF)
USA Soil Conservation Service Method	A rural catchment model	PR = q / p = P / (P +S)
Green-Ampt	An infiltration model for pervious and semi-pervious surfaces - Used in USA in conjunction with SWWM runoff routing model	Infiltration losses are defined as a function of hydraulic conductivity, capillary suction, soil moisture content and volume of water
Horton	An infiltration model for pervious and semi-pervious surfaces - Can be used with the Desbordes or SWWM runoff routing models	Infiltration losses decay exponentially as a function of time

** Terms defined at end of paper*

Table 2: HydroWorks' Runoff Volume (net rainfall) models

Runoff Routing module

Runoff routing models predict how quickly the surface runoff emanating from a given rainfall event enters the drainage system. HydroWorks Ver. 4.0NT, offers five separate 'Runoff routing models'.

Table 3: Runoff Routing Models Available in Hydroworks Ver. 4.0NT

Model file	Comments
Double linear reservoir (Wallingford) model	A double linear reservoir model calibrated for UK sub-catchments of less than 1 ha. **(default model)**
Large contributing area runoff model	A double linear reservoir model developed for UK sub-catchments of up to 100 ha.
SPRINT runoff model	A single linear reservoir model developed for the European SPRINT project.
Desbordes runoff model	The standard routing model used in France. It is a single linear reservoir model.
SWMM runoff model	A non-linear reservoir model developed in the USA.

Table 3: Runoff Routing Models Available in Hydroworks Ver. 4.0NT

CASE STUDY BMP MODELLING EXERCISE: AT-SOURCE ROOF-WATER DETENTION TANKS

Introduction

The work outlined in this section relates to an on-going research project, currently being conducted at the University of Sheffield. This project is attempting to assess the viability of applying a specific 'detention based' BMP methodology: 'at-source roof-water collection', to the UK. 'At-source roof-water collection' refers to the localised collection of storm-water runoff from roofed areas, as opposed to its direct conveyance into the sewer system. Rainwater collected from roofs may be temporarily stored, attenuated and then passed into sewer system; be utilised as a supplementary domestic water supply; or be infiltrated locally. There are a wide variety of roof-water collection systems, ranging from the simple garden water butt through to more complex systems, which can be used to supplement a building's domestic water supply.

The remainder of this section describes a preliminary modelling exercise, which explored alternative HydroWorks methodologies for representing the hydraulic effects associated with 'at-source roof-water collection' schemes.

Modelling Background

The installation of a roof-water collection tank may significantly reduce a building's runoff contribution to the sewer system (Figure 3). Figure 3 was generated using a simplistic Excel model that simulates the rainfall, runoff, storage and overflow mechanisms associated with the simple roof and collection tank system. This model was developed from hydraulic first principles (i.e. initial losses, fixed percentage runoff and mass balance models).

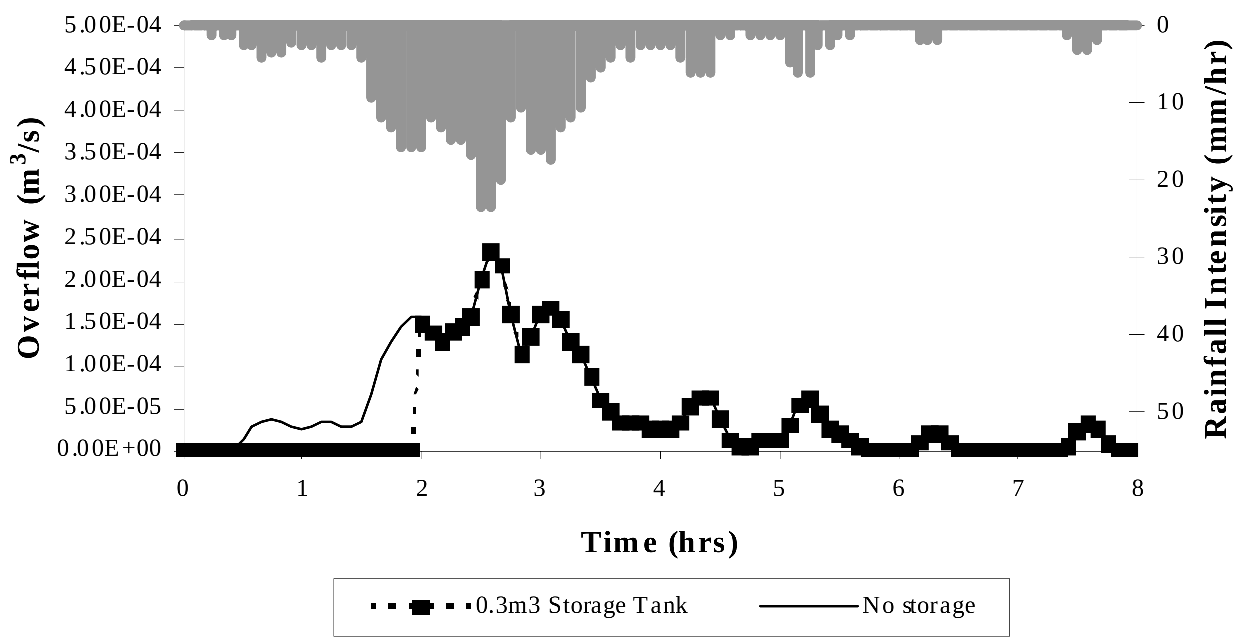

Figure 3: Comparison of runoff emanating from a single 50m^2 roof with i.) a 0.3m^3 storage tank and ii.) no storage

It may be observed in this case that the impact of roof-water collection tank is to retain the runoff component generated during the first 2 hours of the storm. The widespread introduction of roof-water collection tanks would hence be expected to produce attenuation and volumetric reduction of runoff flows emanating from a sub-catchment's roofed surfaces. The magnitude of these impacts would obviously depend upon the number of roof-water tanks introduced, and their individual properties (capacities, feeder and overflow mechanisms).

However from a HydroWorks modelling perspective, there are two major alternative approaches to representing the hydraulic impacts associated with the widespread installation of roof-water collection tanks to a sub-catchment. Both of these approaches are portrayed in Figure 4. The first assumes that all roof-water tanks within a given sub-catchment are identical (i.e. in terms of capacity, volume of contents and connected roof area) and subject to uniform prevailing conditions. The second approach assumes that each roof-water tank within a sub-catchment is unique (i.e. in terms of capacity, volume of contents and connected roof area).

In this example, the 'Identical tanks' profile was generated by directly scaling up the single 0.3m^3 tank profile, from Figure 3, by a factor of 100. In essence, this simulates the hydraulic behaviour of a single 30 m^3 tank, connected to a 5000m^2 roofed area (50m^2 x 100 = 5000 m^2). The non-identical tanks profile was generated using 100 simulations from the simplistic Excel model, which corresponded to randomly generated tank capacities (of between 0 and 0.6m^3). The individual profiles of these 100 simulations were summed together to produce the cumulative profile displayed in Figure 4. It should be noted that the cumulative roof-water storage associated with 'Identical tanks' option is approximately equal to that of the 'Non-identical tanks' option. This relates to the fact that the randomly generated tank capacities that were used to derive the Non-identical tank option ranged from 0 to 0.6m^3, and hence had a mean value of around 0.3m^3.

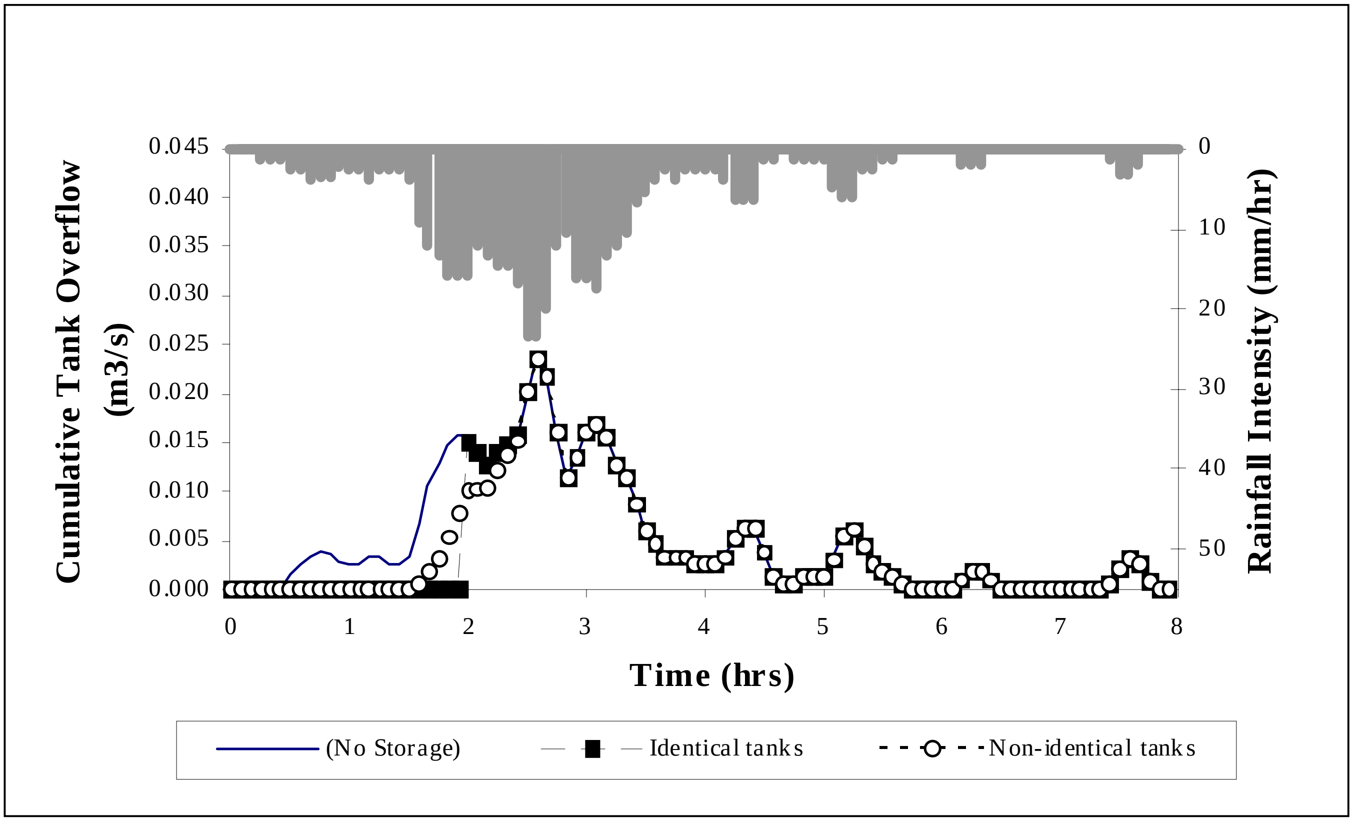

Figure 4: Comparison of runoff emanating from 100x 50m^2 roofs: i.) with No Storage; ii.) Identical Tanks (0.3m^3) and iii.) Non-identical Tanks (randomly generated capacities between 0 and 0.6m^3)

The introduction of 'non-identical tanks' produces a gradual transition from full retention of storm-water to full surface runoff contribution, in contrast to the very sudden transition that characterises the 'identical tanks' scenario. It may be argued that the 'non-identical tanks' model represents real catchment processes more closely than the 'identical tanks' assumption. The following section describes the HydroWorks modelling options which were considered. It should be noted that only one of these options, the Horton approach, attempts to represent the non-identical tank scenario. However, as the cumulative volume stored in both cases is approximately equal, it is not yet clear whether this simplification will pose problems in terms of modelling overall catchment response.

Alternative Modelling Options

A number of alternative HydroWorks modelling approaches for representing 'localised roof-water collection' were considered by this exercise. A brief description of each of these options follows:

Option 1 - Removal

This option assumes that roofs served by collection tanks are completely disconnected from the urban catchment system. In other words, roof-water collection tanks are assumed to never spill.

This approach involves the removal of those roofed areas which are served by collection tanks from the calculation of the Wallingford Procedure (Fixed) PR parameter values. This is achieved by entering a zeroed value of tanked roof-area into the Wallingford Procedure (Fixed) PR and surface weighting equations. This approach may only be used in conjunction with the default set of runoff models.

Option 2 - Low PR

This assumes that the reduction in runoff emanating from roofs served by collection tanks, compared with that from normal roofs, can be reflected by the allocation of a low PR surface in the calculation of the Wallingford Procedure (Fixed) PR equations.

This approach involves using a low PR surface (such as a HydroWorks ‘permeable surface’) to represent roofed area served by collection tanks within the Wallingford Procedure (Fixed) PR equations. This is achieved by entering a low value for the PR(roof area - tanked) parameter in the Wallingford Procedure (Fixed) PR and surface weighting equations. This approach may only be used in conjunction with the default set of runoff models.

Option 3 - Dummy storage

This option relies upon two basic assumptions: firstly, that a single dummy tank can be used to represent the hydraulic behaviour associated with a group of roof-water collection tanks; and secondly, that all roof-water tanks in a given sub-catchment are identical and subject to uniform conditions, and hence spill simultaneously

This approach uses a single dummy tank to represent the hydraulic behaviour associated with a set of individual storm-water tanks. This dummy storage, inserted within the HydroWorks sewer system (i.e. entered within the .dsd file of the sewer module), is used to represent the cumulative storage of a group of roof-water collection tanks. This approach may be used in conjunction with both the default and non-default runoff models

Option 4 - Initial Losses

This option is based upon two fundamental assumptions: i.) that the available pre-storm roof-water storage within a group of roof-water collection tanks may be represented as an initial loss, in conjunction with wetting losses and depression storage; and ii.) that all roof-water tanks in a given sub-catchment are identical and subject to uniform conditions, and hence spill simultaneously

This approach uses the initial losses model to represent the net storm-water required to fill the cumulative available storage within a group of roof tanks. This is achieved by representing the available pre-storm roof-water tank storage as an initial loss for a sub-catchment (i.e. by amending the .rpf file of the runoff module). This approach may be used in conjunction with both the default and non-default runoff models.

Option 5 - User-defined fixed PR runoff

This option is also based upon two assumptions: i.) that all tanks in a sub-catchment spill continuously, and at the same rate; and ii.) that tanks spill for the whole duration (start to finish) of the storm event

This approach involves the use of HydroWorks’ User-defined Fixed Percentage Runoff surfaces. The volumetric reduction in runoff due to roof-water collection is equated to the loss produced by lowering the PR on the model surface. This approach requires the use of non-default runoff models.

Option 6 - Horton Infiltration model

This option assumes that all roof-water tanks in a given sub-catchment are not identical, or subject to uniform conditions, and hence do not spill simultaneously, or uniformly. The Horton infiltration equation is adapted to describe an exponential increase in tank overflow.

This approach involves the use of the Horton infiltration model to represent the cumulative behaviour of a group of non-identical roof-water collection tanks. The varying PR Horton surface is used to represent the incremental increase in runoff volume (i.e. from tank overflows) emanating from a group of roof-water collection tanks. These tanks are not assumed to spill simultaneously, or uniformly. This approach requires the use of a non-default runoff model.

Note: It is clear that these approaches form two groups: i.) Options which may be applied under both default and non-default runoff models, and ii.) Options that may only be applied under one of these two runoff modes. Within the UK, HydroWorks catchment models are typically generated using HydroWorks default settings. However, it is envisaged that the use of the non-default New UK (Variable) PR model will became more common over the course of the next decade. It would hence be advantageous to identify a HydroWorks' modelling approach that could represent the hydraulic behaviour of 'localised roof-water controls' under both default and non-default runoff conditions.

Modelling Procedure

A simple one-node case study sub-catchment was used to investigate the performance of each of the proposed modelling options. This sub-catchment was assumed to consist of 5000 m^2 of roofed area, directly connected to water collection tanks (with a cumulative volume of 30m^3). These tanks were assumed to overflow directly into the local sewer network. The catchment configuration is illustrated within Figure 5. This scenario was intended to represent the roofed area in a sub-catchment containing 100 x 50 m^2 roofs, each connected to an individual 0.3m^3 collection tank.

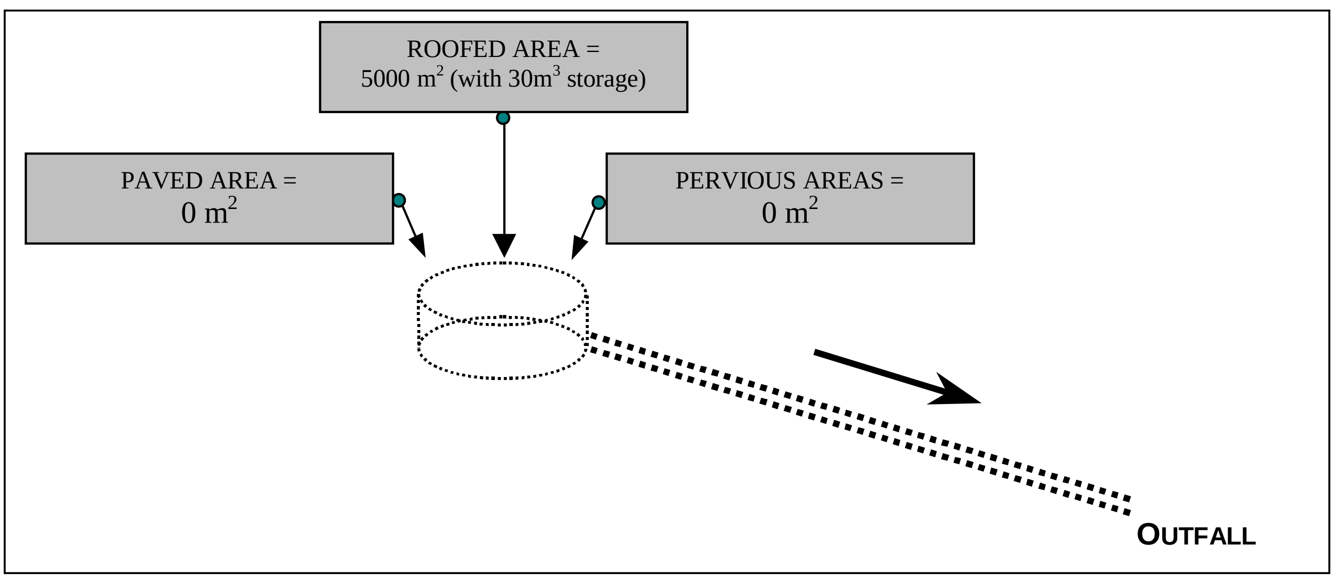

Figure 5: One-node case study sub-catchment

Each of the modelling options presented in Section 3.3 was used to simulate the outflow hydrograph corresponding to ten separate input rainfall events. These scenarios were also simulated using the simplistic Excel model described in section 3.2.

The two main aims of this comparative modelling exercise were: firstly, to provide a quantitative comparison between the results obtained from each of these proposed modelling techniques; and secondly, to allow an assessment to be made relating to the logistical implications associated with each option.

Results

The results of this exercise indicated that the 'Initial Losses' option was the most appropriate of the potential modelling options. The rationale behind this decision was as follows.

The 'Removal', 'Low PR' and 'User-defined Fixed PR' options were each rejected because of the modelling simplifications they employed. These simplifications lead to predicted overflow profiles that significantly differed from those anticipated (i.e. those predicted by the theoretical Excel model). The 'Removal' and 'Low PR' generated no tank spill, whilst the 'User-defined Fixed PR' option produced a spill profile that resembled a scaled down version of the rainfall input profile.

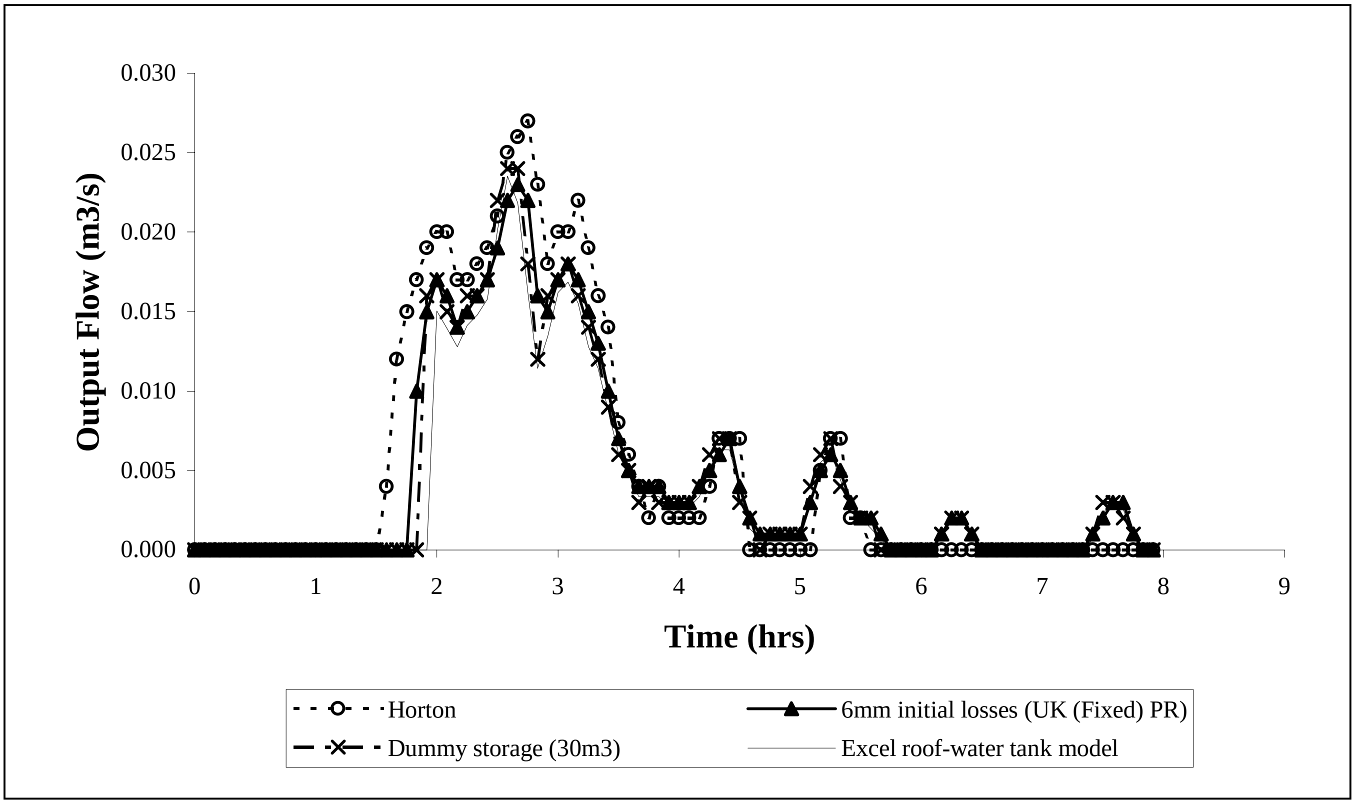

Figure 6: Comparison of alternative modelling options for representing spill overflow from a group of rainwater tanks - (Rainfall Input: Low3.red)(Cumulative roofed area: 5000m^2 and Cumulative tank storage: 30 m^3)

The elimination of these options left the 'Dummy storage', 'Initial Losses' and 'Horton' options. Of these approaches, the 'Horton' option, which uses a varying PR surface to represent spill from a group of non-identical tanks, appeared to be based upon the most accurate modelling assumptions (i.e. that all tanks in a group do not spill simultaneously). However, the results generated by this approach did not appear to be significantly different from those generated by the 'Dummy storage' and 'Initial Losses' options (which both use a single representative tank approach) (Figure 6). Of these three approaches, the 'Initial Losses' option was considered to form the most direct and transparent technique. It is possible to use this approach to directly define tank storage as an initial loss corresponding to an existing sub-catchment surface, whereas the other two approaches rely on more in-direct methods of defining tank storage within HydroWorks. In essence, this approach may be implemented to existing HydroWorks catchments data with minimal changes having to be made to the original model. This transparency means that results obtained using this method may be easily checked, and hence treated with a higher degree of confidence than results obtained from the other approaches.

Summary and Conclusions

The work outlined in this section relates to a preliminary modelling exercise, conducted at the University of Sheffield, during the early stages of a PhD research project. This modelling exercise sought to identify an appropriate methodology for representing the hydraulic impacts of roof-water collection schemes using the HydroWorks model. Roof-water collection may be broadly defined as a 'dentention based' BMP technique.

The 'initial losses' solution was identified as the most appropriate HydroWorks modelling approach for localised roof-water detention schemes. However, it is recognised that as the results of this exercise are limited to a simple one node catchment, further work needs to be conducted before this approach may be more widely recommended. Further work is currently being conducted to assess the applicability of this approach to larger HydroWorks models, which correspond to real UK urban catchments.

Representing 'Infiltration-Based' BMPs With Infoworks

The modelling methodologies presented within Section 3 were developed to represent the hydraulic behaviour of 'detention-based' BMP techniques (e.g. roof-water collection tank and holding ponds) and are hence not directly applicable to 'infiltration-based' BMP techniques (e.g. infiltration trenches, porous pavements and soakaways). Previous attempts have been made to represent 'infiltration-based' BMP techniques using the current HydroWorks model (Monster et al, 1998). These utilised combinations of dummy nodes and links to represent the hydraulic behaviour associated with a range of infiltration-based BMP techniques. The published methodology relating to these modelling approaches is somewhat unclear. However, it is envisaged that the application of these techniques would not be entirely appropriate for large-scale catchment simulations using HydroWorks.

This section presents an infiltration module that has recently been developed for InfoWorks, by Wallingford Software. It is envisaged that this new model will be well suited for the modelling of 'infiltration-based' BMP techniques. The 'Infiltration Module' is used to represent 'rainfall induced infiltration' inflow to the sewer system. This enhances the existing ability of HydroWorks and InfoWorks to represent constant infiltration flow or time varying population or dry weather flow.

The conventional HydroWorks model considers rainfall to be initially stored in surface depressions (see Initial losses models - Section 2). When rainfall exceeds depression storage, a proportion of the excess rainfall begins to form runoff (see Percentage Runoff equations – Section 2). The remaining rainfall is considered as being lost from the modelled system. However, within the proposed InfoWorks infiltration module this remaining rainfall would be directed into the soil storage reservoir. When this soil reaches a given saturation threshold (percolation threshold), water would be considered to start percolating downwards. A proportion of this percolation flow (percentage infiltrating) would be assumed to infiltrate directly into the sewer network, whilst the remainder would be represented as penetrating deeper to feed the groundwater storage reservoir.

The Infiltration Module is currently undergoing evaluation and calibration of default parameters. It is available free on request, in experimental state to InfoWorks customers. It will be included as standard in the release of v2.5 of InfoWorks, which is due later this year.

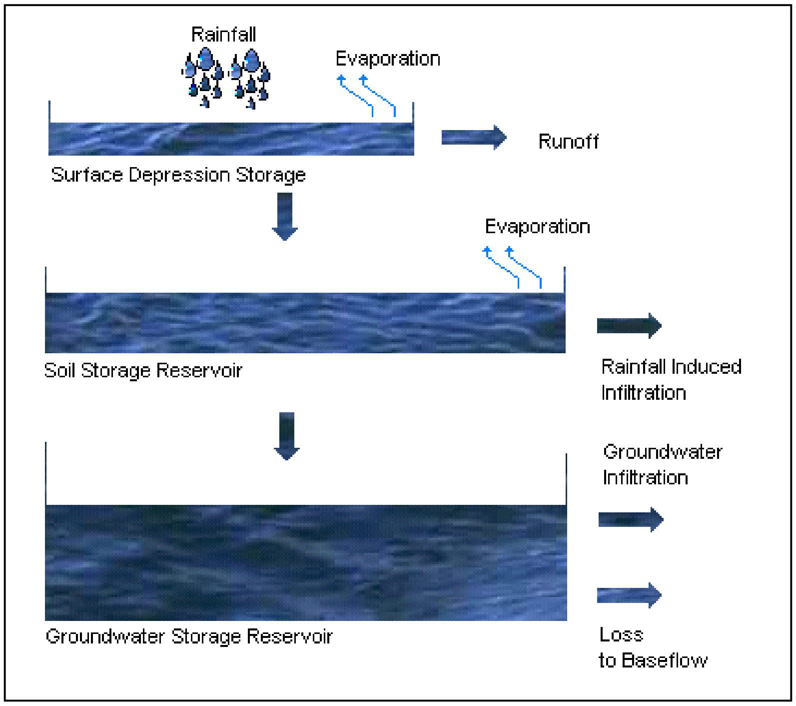

Figure 7: Schematic of proposed InfoWorks 'infiltration module' for representing rainfall-induced infiltration inflow to the sewer network

RECOMMENDATIONS FOR FUTURE WORK

Having provisionally demonstrated that 'detention-based' BMP techniques can be represented within HydroWorks (Section 3) it is recommended that further work be conducted in order to establish procedures for modelling other structural BMPs particularly infiltration-based BMP techniques, such as infiltration trenches, porous pavements or swales. It is envisaged that the new 'infiltration module', highlighted in Section 4, will play a key role in this process.

A number of relevant existing studies have been identified (McKissock, 1999; Monster et al., 1998). It is recommended that any future work draws upon this previous experience, and ultimately seeks to pool together a set of guidelines for modelling a range of BMP techniques using HydroWorks/InfoWorks. These modelling guidelines could potentially be incorporated within future versions of HydroWorks/InfoWorks (e.g. within the on-line help facilities).

It is felt that the inclusion of BMP techniques within future releases of HydroWorks/InfoWorks, and other similar modelling packages, would form an important step in the promotion of sustainable urban drainage within the UK.

REFERENCES

1. Ashley R., Morrison R., Flemming R. and Jefferies, *Application of a Computer Model for BMP Performance Assessment and Comparison Between UK and German Design Practice*, UDM98 Conference Proceedings, Vol. 2, pp. 513-520, 1998
2. CIRIA Project Report 123, *Scope for control of urban runoff*, Vols 1& 2, 1992
3. CIRIA Research Project 555 – Website, *Sustainable Urban Runoff Management*, http://www.sepa.org.uk/guidance/scontrol/ciria/ciria.htm 1999

4. McKissock K., MSc. Dissertation – *A cost effective alternative for dealing with urban stormwater drainage*, Department of Civil Engineering, University of Abertay Dundee, Bell Street, DUNDEE, DD1 1HG 1999

5. Monster N., Klein M., Clemens F., *Modelling for Sustainable Urban Water management: Hydrodynamic Calculations as a Decision Tool*, UDM98 Conference Proceedings, Vol. 2, p. 529, 1998

6. National Water Council, *Design and Analysis of Urban Storm Drainage – The Wallingford Procedure, Principles, Methods and Practice*, 1981

7. Ristenpart E., *Planning of Stormwater Management with a New BMP Model*, UDM98 Conference Proceedings, Vol. 2, pp. 506-512, 1998

8. Saul A.J., Chapter 6: *Urban Drainage Modelling, Sewers rehabilitation and new construction repair and renovation*, Edited by G. F. Read with I.G. Vickridge, Arnold, London, 1997

DEFINITIONS

c	=	constant
PIMP	=	Percentage of impervious area in a given sub-catchment
UCWI	=	Urban Catchment Wetness Index
SOIL	=	An index of water holding capacity of soil
IF	=	Effective Impervious Area Factor
NAPI	=	AP130 - derived from net rainfall after subtraction of running depression storage
P	=	Cumulative rainfall from start of storm
S	=	Storage depth
Q	=	Cumulative runoff from the start of the storm