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A review of models for low impact urban stormwater drainage

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Abstract

Low-impact development urban stormwater drainage systems (LID) are an increasingly popular method to reduce the adverse hydrologic and water quality effects of urbanisation. In this review, ten existing stormwater models are compared in relation to attributes relevant to modelling LID. The models are all based on conventional methods for runoff generation and routing, but half of the models add a groundwater/baseflow component and several include infiltration from LID devices. The models also use conventional methods for contaminant generation and treatment such as buildup-washoff conceptual models and first order decay processes, although some models add treatment mechanisms specific to particular types of LID device. Several models are capable of modelling distributed on-site devices with a fine temporal resolution and continuous simulation, yet the need for such temporal and spatial detail needs to be established. There is a trend towards incorporation of more types of LID into stormwater models, and some recent models incorporate a wide range of LID devices or measures. Despite this progress, there are many areas for further model development, many of which relate to stormwater models in general, including: broadening the range of contaminants; improving the representation of contaminant transport in streams and within treatment devices; treating baseflow components and runoff from pervious surfaces more thoroughly; linkage to habitat and toxicity models; linkage to automated calibration and prediction uncertainty models; investigating up-scaling for representation of on-site devices at a catchment level; and catchment scale testing of model predictions.

Keywords: Stormwater; Catchment; Model; Review; Urban drainage; Low impact

1. Introduction

Worldwide, there is a well documented decline in habitat and water quality of urban streams. Urbanisation is typically accompanied by increases in impervious surfaces such as roofs and roads, construction of hydraulically efficient drainage systems, compaction of soils, and modifications to vegetation. This results in increased flood flows (Leopold, 1968) and stream erosion (Hammer, 1972), and the potential for decreased baseflow (Paul and Meyer, 2001; Schueler, 1994). Urbanisation also leads to water contamination from suspended sediments, heavy metals, hydrocarbons, nutrients, and pathogens (Burton and Pitt, 2001; Hall, 1984).

In the last two decades, new urban water management approaches have been developed to deliver improved environmental, economic, social and cultural outcomes. We term such an approach LID (low impact development), but alternative acronyms are SUDS (sustainable urban drainage systems), WSUD (water sensitive urban design), and LIUDD (low impact urban design and development, a term used in New Zealand). In this review, we focus on stormwater aspects of LID, with limited attention to broader issues of integrated urban water cycle management. The scope is also limited to the effects of stormwater on water quality and quantity, rather than visual, social and economic impacts.

LID devices are designed to detain, store, infiltrate, or treat urban runoff, and so reduce the impact of urban development

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(e.g. Wong et al., 2002; NZWERF, 2004). LID devices include structural measures such as wetlands, ponds, swales, rainwater tanks, bioretention devices, vegetated filter strips, and filter strips. LID approaches also include non-structural measures such as alternative layouts of roads and buildings to minimise imperviousness and to maximise the use of pervious soils and vegetation, contaminant source reduction, and programmes of education to modify activities. LID particularly emphasises on-site small-scale control of stormwater sources. Many design guidelines for such devices are now available (e.g., CIRIA, 2000).

Despite an increasing awareness and knowledge of these issues and potential solutions, the transition to more sustainable urban drainage design has been slow. This may reflect, among other factors, a dearth of LID drainage design tools that operate effectively at the necessary range of scales. The availability of effective LID modelling software could act to encourage wider uptake of LID principles (Beecham, 2002). Tools can make design and application of LID more efficient, and demonstrate outcomes that can be used for education and policy development. The challenge is to translate complex and highly variable natural processes into a computerised system or tool that allows straightforward evaluation of LID drainage measures at a range of scales applicable to urban management.

This paper explores the current range of LID assessment tools, discusses their strengths and weaknesses and puts forward future research needs, with the aims of aiding model selection, increasing awareness of the available models, and encouraging model development.

1.1. Previous reviews

Zoppou (2001) reviewed both quantity and quality aspects of urban stormwater models. He provided an overview of stormwater modelling approaches, with a concise mathematical description of common methods for flow routing and contaminant generation and transport. He also described several stormwater models. Burton and Pitt (2001, Appendix H) reviewed catchment and receiving water modelling in relation to stormwater. They classified the catchment models primarily according to the complexity, ranging from simple methods (based on export coefficients or event-mean concentrations multiplied by runoff volume) through to complex models that are typically spatially distributed and processed based. McAlister et al. (2003) reviewed urban stormwater quality models, and stressed the importance of using suitably small temporal resolution and continuous simulation over one or more years. Beecham (2002) presented key features of four models for water sensitive urban design, but did not compare and contrast the models or discuss their suitability. Other reviews of contaminant models (e.g. the review of sediment models by Merritt et al., 2003) are not focussed on urban stormwater or LID.

These previous reviews provide a valuable background on the features of a range of models, methods for representing key processes, and categorisations of the models. However, none of them focus specifically on the ability of the models to represent LID. In this review the focus is urban stormwater models and LID.

1.2. Review process and structure

We identified approximately 40 models for urban stormwater from previous published reviews, journal abstracting services, internet searches, conference proceedings, and modelling practitioners. We then selected 10 models that are currently available and have not been superseded, have sufficient documentation in English, and are more than a conventional stormwater drainage/hydrology model. Our assessment is based on versions of the models available in February 2005, and the range of models and the features of the models may have changed since that time.

The ten models (Table 1) were compared in relation to the following attributes:

- The intended uses of the model including research, public education, developing device sizing rules, catchment planning, and conceptual to detailed design. All these levels of model use are relevant to LID.
- Temporal resolution and scale. The temporal resolution refers to the smallest computational timestep of the model. We also distinguish between models intended only for a single rainfall event and those intended for simulation of a long-term sequence of events (continuous simulation) as discussed in Singh (1995).
- Catchment and drainage network representation, and spatial resolution and scale. The catchment and drainage representation refers to the types of element that are used to represent the catchment, soil column and groundwater, drainage network, and treatment or flow control devices. We categorise models according to whether they are lumped (a single catchment element), quasi-distributed (where the model is broken into a number of elements such as subcatchments), or fully distributed (usually grid or mesh-based) as discussed in Singh (1995). In each of these categories, we include cases where the catchment element is broken down into a number of land uses, surface types or stormwater treatment categories. Spatial scale refers to the size of the modelled area.
- Representation of runoff generation, routing to the drainage network, routing within the drainage network, and groundwater movement.
- Types of contaminant included in the models, and methods used to represent processes of contaminant generation, transport and treatment.
- LID devices or technologies specifically included in the model, or able to be simulated indirectly using the model. The devices assessed range from on-site non-structural controls such as reduction of imperviousness, to regional scale wetlands.
- User interface and integration with other software such as automated calibration software or receiving-water models.