BEST PRACTICE FOR MODELLING SUSTAINABLE URBAN DRAINAGE SYSTEM STRUCTURES

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Abstract
Sustainable Urban Drainage Systems (SUDS) design has traditionally been simplistic, using basic equations and "rules of thumb" often leading to conservative designs. Now with plenty of information available advising planners about the different types of SUDS structures available it is often left to engineers to build or develop hydraulic models to quantify how these structures will operate for a range of operating conditions. This paper will explore how SUDS design on a range of real life case studies compare using a detailed modelling approach against traditional approaches. The results show the benefits of modelling from a SUDS perspective, where traditionally little modelling has been undertaken.

Introduction
This paper demonstrates how the use of modelling can be used to provide a good representation of real life SUDS networks. The paper will focus on the modelling software called InfoWorks Collection Systems (IWCS) which is produced by Wallingford Software. As SUDS are more widely implemented, the importance of the ability to model SUDS is becoming more apparent. There are several uses for SUDS modelling, from the initial design stage through to post project appraisal. Four possible uses are summarised below:

- Improved optimisation of small SUDS designs.
- Use as a design tool for large industrial or residential developments
- Integration of SUDS networks into larger catchment models to assess the effects SUDS networks have on the surrounding catchment;
- Use as an audit tool to assess the current and future operation and maintenance of SUDS.

IWCS has the ability to replicate the hydraulics of SUDS systems. Examples of some of the changes are as follows:

- Improved representation of infiltration losses;
- Introduction of the 'pond' node;
- Permeable flows – Darcy's Equation;

These changes allow SUDS techniques such as Ponds, Swales, Permeable/Porous Pavements, Soakaways, Infiltration trenches and Plastic Storage Boxes to be represented more accurately. This paper uses real life SUDS examples to put these new features to the test and assess the benefits of modelling SUDS. Two case studies are used in this investigation to demonstrate the reliability of the SUDS module within IWCS. Case Study 1 will be used to demonstrate the representation of infiltration losses in a conduit. Case Study 2 will be used to demonstrate the pond node and the effect of infiltration rates as ponds fill and empty.

Case Study 1: Salford Sports Village
The aim of this case study is to demonstrate the effect of infiltration losses in a conduit, and the extent to which it is affected by contributing factors such as infiltration rate and porosity within the conduit. These two contributing factors are particularly important to assess as these can change over time due to build up of silt within the conduit. Salford Sports Village has

already been designed and constructed. This initial design brief was a storm water drainage system for amenity buildings and car park, to withstand a 1 in 100 year RP event. The conditions of the site are favourable for infiltration as the ground is made up of clayey sands and gravels with a soil permeability rate of 3x10-5m/s. The impermeable area of the site is 6000m2. By using a traditional approach, it was estimated that 155m3 of attenuation storage is required on site.

The SUDS structure design utilised plastic geocellular boxes below the car park permeable surface, which have low depth/high base area ratio encouraging infiltration and reducing construction costs. (Figure 1)

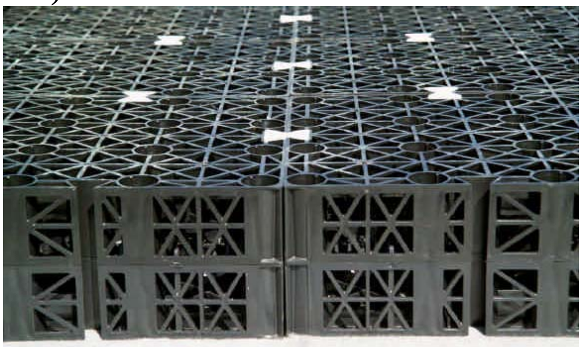

Figure 1- Example of plastic geocellular boxes as used in Case Study 1

Modelling Methodology

In this simple model a single ‘infiltration trench’ conduit was constructed in IWCS using the permeable flow solution model to provide:

- 155m3 storage (D 0.15m x L 215m x W 4.8m)
- Infiltration rate for the site 3x10-5m/s (108mm/hr)
- Porosity of 92% to represent void ratio of ‘Charcon Permavoid’ Plastic Boxes (as used in this project)
- Hydraulic conductivity through unit of 0.0174m/s (fast)

Modelling Results

In this case a range of constant intensity rainfall profiles with durations between 5 and 240 minutes were simulated through the conduit, for a 1 in 100yr return period. The maximum volume simulated in the conduit during all the events was 112m3 as seen in Figure 2. This is approximately 43m3 less than the total storage volume available. However this does not take into account any factors of safety for operational issues or time varying rainfall, which would have been included in the initial design. It does however confirm that the original design was valid and that results are replicated to a good degree, although perhaps is slightly over designed.

Further investigation of the effect of changing infiltration rates and porosity and running the model with time series rainfall allows the designer to build in a factor of safety to the design easily and efficiently. The factor of safety takes into account operation and maintenance issues that may present problems over time as the performance of the system begins to deteriorate and accounts for variability in soil permeability. Modelling the system should allow potential issues to be highlighted at the early design stage, so that appropriate measures can be incorporated into the design and where necessary added into the Operation and Maintenance Manual to avoid substandard performance.

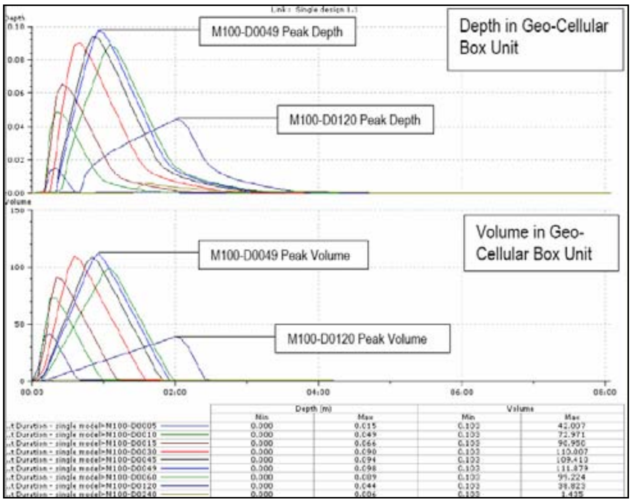

Figure 2 – Depth and volume in permavoid unit during a constant rainfall event.

Effect of Infiltration Rate on System Performance

Figure 2 demonstrates that the critical duration event for this particular conduit is M100-D0049 with the largest maximum peak volume. Therefore this event was used in the next stage of analysis, which was to test the effect that changing the infiltration rate has on the depth of water within the conduit. A range of infiltration rates between 30 and 180mm/hr were tested to assess the effect on the water level within the conduit.

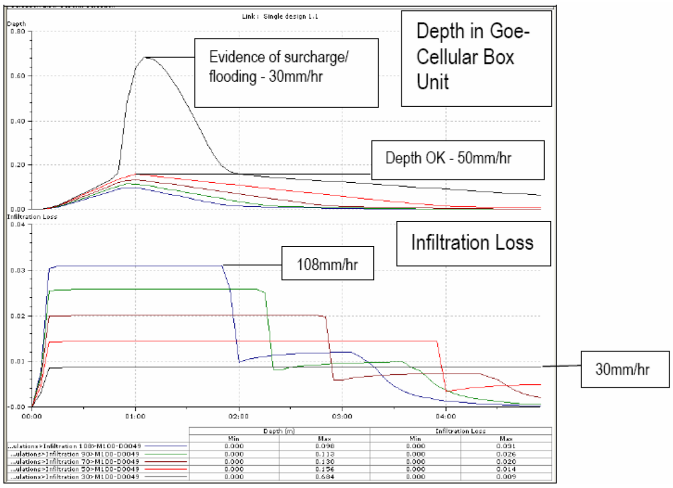

Figure 3 – Change in depth as infiltration rate changes.

As would be expected, Figure 3 demonstrates that as the infiltration rate is reduced the depth of water in the conduit rises, until it reaches a point where there is no longer enough capacity in the system and it shows signs of flooding/ surcharging. This can be seen by the large peak on Figure 3. In this case the critical infiltration rate is somewhere between 30mm/hr and 50mm/hr. This gives enough information for the designer to decide if they require a larger or smaller factor of safety incorporated into the design of the system. In this case, the model simulations suggest that the factor of safety is in the order of 5. Although engineering judgment is still necessary to determine what factor of safety is required, the model is very useful to determine how the overall performance will change based on alteration of contributing factors.

Effect of Porosity on System Performance

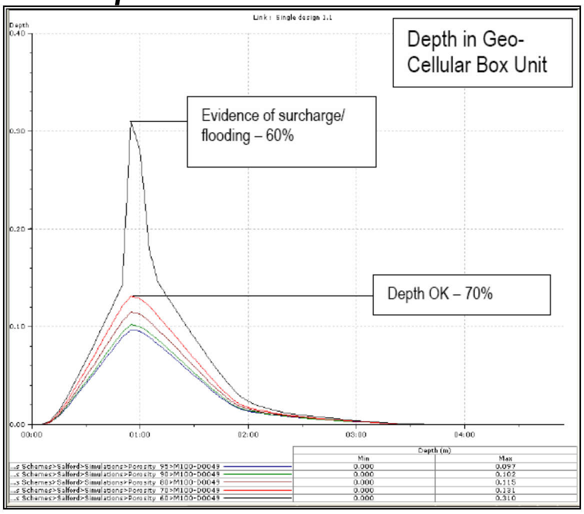

Figure 4 – Change in depth as porosity reduces.

The final section of the performance analysis of Case Study 1 assesses the effect of changing the porosity on the depth of water within the conduit. The range of porosity values used to assess the performance of the system are between 60% and 95%. As would be expected Figure 4 demonstrates that as the porosity is reduced, the depth of water within the conduit increased. This graph identifies the critical porosity value between 60% and 70%. In reality if silt fills up more than 35% of the open volume of the geocellular boxes the system is likely cause flooding. Knowledge of this early on means it can be incorporated into the design of the system.

Whole Network Performance Analysis

The initial analysis was undertaken on just one conduit to test the performance of IWCS in a simple manner. IWCS is a powerful tool when the network is larger or contains a series of components, as the effect of making simultaneous changes to the design can be assessed just a easily as making one change. A network of further pipes and nodes were added to this model to replicate the individual tanks of geo-cellular box units throughout the site. Previously they were represented as one large tank. The overall network can be seen on Figure 5.

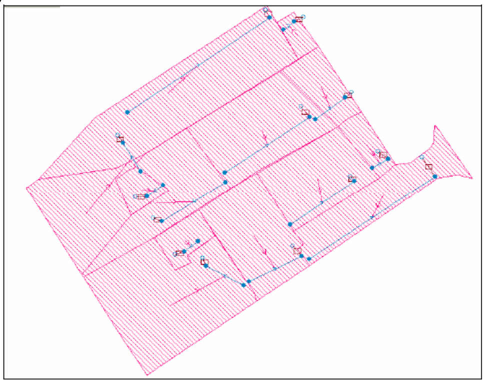

Figure 5 – Larger network of pipes at Salford Sports Village to replicate whole system

The infiltration rate was set to 72mm/hr to allow for a factor of safety in the design and each of the tanks were individually sized. All the conduits were set to the same porosity, infiltration rate, conductivity etc. The only difference between the tanks was the size of the geo-cellular boxes. Table 1 shows the surcharge depth for tanks with different sized contributing areas. From this model the tanks that are likely to surcharge or flood (highlighted in pink) are quickly identified and can be resized accordingly. The benefit of modelling SUDS designs becomes more apparent when trying to design more complex systems.

US Node ID	Max DS Depth (m)	Max US Depth (m)	Depth of Surcharge	Height of Box (mm)
Tank10a	0.312	0.334	0.162	150
Tank11a	0.28	0.332	0.13	150
Tank12a	0.137	0.142	-0.013	150
Tank13a	0.153	0.16	0.003	150
Tank1a	0.128	0.133	-0.022	150
Tank2a	0.069	0.08	-0.081	150
Tank3a	0.268	0.271	0.118	300
Tank4a	0.107	0.116	-0.043	150
Tank5a	0.433	0.46	0.283	150
Tank6a	0.13	0.135	-0.02	150
Tank7a	0.099	0.105	-0.051	150
Tank8a	0.379	0.386	0.229	150
Tank9a	0.521	0.54	0.371	300

Table 1 – Individual geo-cellular tanks assessed for depth of water in the tank.

Case Study 2: Site X

The aim of Case Study 2 is to assess the performance of the pond node which allows infiltration from both the side of the pond and the base of the pond, taking into account vegetation and a liner in the base of a pond. Site X is a new housing development of approx 5ha, which has been built but cannot be identified due to client confidentiality. The model built for Site X was part of an audit of the surface water system post-construction. The model does show some flooding issues, which tie in with real flooding issues that have been recorded on site. Therefore if modelling has been used as part of the design process, it may be that some of the problems may have been avoided. The system is mainly large conventional pipes to provide attenuation, and flow is controlled using orifices. The system has a limited outfall and therefore any flows, greater than the orifice control, are initially attenuated and then overflow into an infiltration basin, which has an emergency overflow into the local water course.

Infiltration Basin Modelling – Pond Node Parameters

Modelling Methodology

The infiltration basin was modelled using a pond node, and a range of infiltration rates were used to assess the performance of the pond.

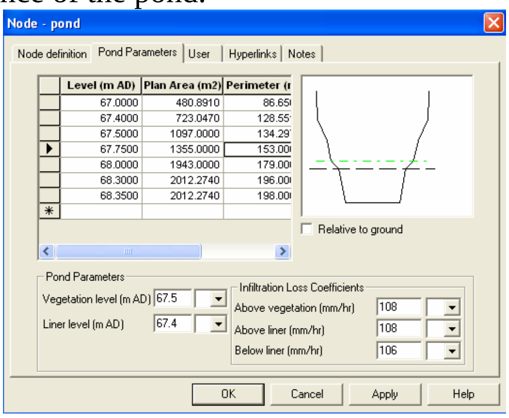

Figure 6 - Pond Parameters

Infiltration loss coefficients can be specified for three different parts of the pond which are above the vegetation level, between the vegetation and liner levels and below the liner level. This allows different infiltration rates to be applied to the base and the sides of the basin. If the pond is contained within a single subcatchment, any rainfall that falls on the dry part of the catchment will be subject to normal runoff conditions, however any direct rainfall into the wet area of the pond will be assumed to have no losses associated with it and 100% runoff. When simulating using the pond node, evaporation is also taken into account based on the surface water area and the evaporation rate.

Modelling Results

In this case study the effect of changing the infiltration loss coefficients on the pond performance is assessed against pond water level. The infiltration rates used lie in the range 10mm/hr to 200mm/hr. These were used to assess the different drain down times for the basin.

Figure 7 demonstrates how the drain down times for the basin increase as the infiltration rate is reduced. At an infiltration rate of 100mm/hr the pond takes approximately 18hrs to drain down. If the infiltration rate is much lower than 100mm/hr the basin takes longer than a day to drain down. The sensitivity testing demonstrates the importance of variations in soil permeability and drain down times. The generally accepted ‘rule of thumb’ is that ponds or tanks should be able to half-empty within 24hrs to reduce the risk of overtopping due to successive storms. In systems like this one, it is sensible to assess Time Series Rainfall to test how critical this lengthy drain down time is against real rainfall data.

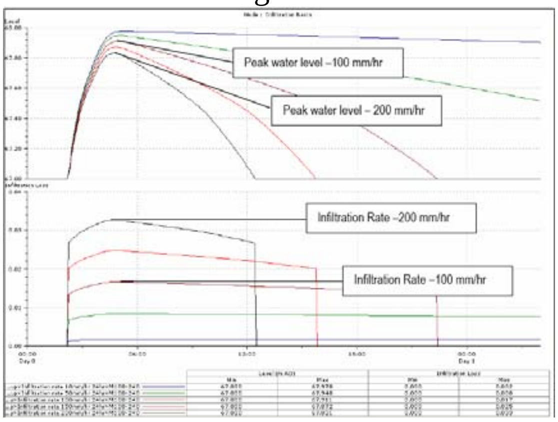

Figure 7 – Effect of infiltration rate on pond level

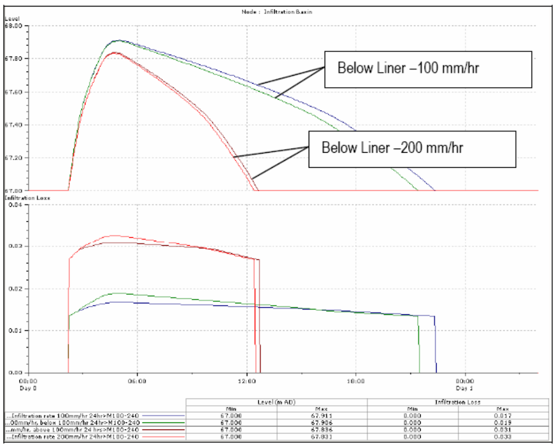

Figure 8 – Effect of changing infiltration rate below and above the liner

Figure 8 demonstrates the effect of changing the infiltration rate below the level of the liner and above the level of the liner based on the pond parameters given in Figure 6. The graph indicates that changing the infiltration rate below the level of the liner has a much greater effect than changing the infiltration rate above the liner. This is due to the fact that the base area is below the level of the liner and is the largest surface area through which infiltration occurs. However this does clarify that the pond node is simulating infiltration as expected.

Figure 9 – M100-240 design event peak flows across whole model

Figure 9 shows the whole model which has been iteratively improved from the original design to stop any flooding occurring. This model can either be used

- on its own to continue to optimise the design requirements
- to assess the required factor of safety to account for deterioration over time
- to determine the effects in a larger storm model of Leicester
- in integrated catchment modelling to assess impacts on watercourses.

Time series rainfall could also be applied to the whole model to assess the effect that real rainfall data has on the model, and understand how it would deal with multiple peak storms or continuous rainfall rather than just the design events used in this investigation. Due to the large amount of storage within SUDS system and the slow flows through the system, different types of events may have a more significant effect than they would have in traditional pipes where flow tends to be much quicker.

Conclusion

This paper has highlighted there are many benefits of using IWCS to model SUDS systems, however a significant amount of engineering judgement and a good knowledge of SUDS components is still required to ensure that any changes made to the design would be appropriate on site to suit the client requirements and the site conditions. The main benefits of modelling SUDS that have been identified in this paper are summarised below:

- Optimisation of a SUDS design
- Assessment of operation and maintenance issues at the design stage
- Assessment of the effect of a SUDS network on a larger catchment
- Sensitivity testing
- Design check against a range of rainfall types and profiles including time series rainfall.
- Allows failure modes to be assessed.