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# Retrofitting to manage storm overflows - A case study in Southwest England

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## Abstract
This study developed a simplified 1D hydraulic model to quantify field runoff entering a combined sewer network in a catchment in southwest England. This model uses the Green-Ampt model to represent the infiltration process and a reservoir routing model to represent the runoff routing. The modelled field runoff was input into the existing sewer network model as inflows in InfoWorks ICM to analyse the contributions of various components to storm overflows. The simulations revealed that storm overflow frequency is primarily driven by impermeable area surface runoff, overflow duration is mainly affected by ground infiltration, and field runoff significantly contributes to overflow volume. Nature Based Solutions (NBS) and Sustainable Drainage Systems (SuDS) were implemented within the model to evaluate their effectiveness in mitigating storm overflow through long-term simulations. Results indicated that together with an NBS pond, retrofitting 8% of impermeable surfaces with SuDS can reduce storm overflow frequency by 38%, overflow duration by 40%, and overflow volume by 77%, highlighting the potential of these interventions to minimise storm overflow impacts.

## Highlights
- Inflow from a field into a combined sewer network was modelled by a simplified 1D model.
- The contribution of various components to storm overflows in the catchment was analysed.
- The effectiveness of NBS and SuDS in reducing storm overflows was assessed within the model.

## Introduction
Storm overflows act as a relief valve to release excess drainage water into a receiving water body to reduce pressure on the network. The UK Department for Environment, Food and Rural Affairs (Defra) states that the current use of storm overflows needs to be reduced, and the 2023 Storm Overflow Discharge Reduction Plan targets removing overflows outside of extreme rainfall events by 2050. Storage techniques such as in-sewer tanks that temporarily retain excess stormwater for later release have been widely used in the UK (FWR 2018). However, Defra now encourages a natural capital-based approach, urging water companies to increase the use of Nature Based Solutions (NBS) and Sustainable Drainage Systems (SuDS) to reduce flows through the catchments. These methods would offer the potential to reduce the frequency of storm overflows while delivering ecological benefits through the temporary storage of stormwater and promoting the natural hydrological cycle. This study focuses on a site in southwest England to: a) Quantify the field runoff entering combined sewers, a factor which

is often overlooked in existing sewer models; and b) Assess the effectiveness of NBS and SuDS in reducing storm overflows.

# Methodology

### Study Site

The selected study site is a village in the Tamar River catchment, located in southwest England. Geographical Information System (GIS) identifies this site has a large field area that contributes to the combined sewer within the catchment, and the Event Duration Monitoring (EDM) data suggests that the storm overflow frequency exceeds the targets set in the Storm Overflow Reduction Plan. These factors make this site a candidate for implementing NBS and SuDS to mitigate storm overflows. Figure 1(a) shows the existing sewer network. The existing sewer system comprises both combined and separate (highlighted in red) systems. The division of drainage sub-catchments and contributing areas is based on an impermeable area survey, with approximately 1.3 ha of surface runoff entering the combined sewers. This site has two storm overflow locations: SO1 on the sewer network and SO2 at the inlet to the Sewage Treatment Work (STW). Figure 1(b) presents the study site topography. The field soil in the northeast of the study site was categorised as loam by the Land Information System and based on the soil type it was estimated that it has an infiltration rate of approx. 1.0 mm/hr – 10.0 mm/hr. The relatively slow infiltration rate and the steep slope in the field may lead to significant surface runoff entering the combined sewer, but this was not represented in the existing sewer model.

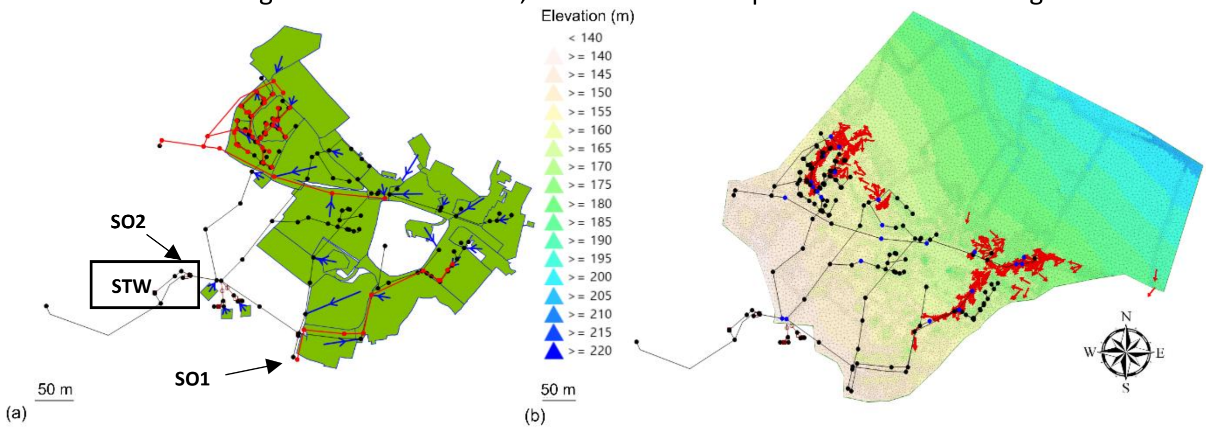


**Figure 1.** Study site, (a) Existing Sewer Network (Storm Sewer highlighted in Red); (b) Elevation (filled colours) and Modelled Flow Path (red arrows).

### Quantifying Inflows from the Field

Initial simulation was conducted in InfoWorks ICM for the entire study site using a coupled 2D-1D approach, where the whole site was modelled as a 2D surface and the existing sewer was modelled as 1D. The connection between the 2D and 1D models was built through the manholes. This simulation used a 1-in-1-year, 2-hour design storm to identify the field runoff that enters the sewer network. More detailed simulations were then conducted with the identified field with 24 design storms, covering return periods from 1 to 40 years and durations from 15 minutes to 2 hours. While the 2D-1D approach in InfoWorks ICM provides detailed simulations on the flow depth and velocity in the 2D surface, it is computationally intensive (e.g. it takes 3 hours to run a 6-hour rainfall simulation) and unsuitable for long-term simulations (e.g. a year simulation) for annual storm overflow analyses. To overcome this limitation, a simplified 1D modelling approach was developed. This approach models infiltration using the Green-Ampt model and flow routing using an empirical reservoir routing equation (Eq.1). The empirical parameters ($k$ and $n$) in the equation were calibrated to match hydrographs from the 2D InfoWorks ICM simulations. The simplified model and calibrated parameters were then used with real rainfall events and the results were compared with the results from the InfoWorks ICM.

$$Q(t) = kh^n \tag{1}$$

where $Q(t)$ is the flow at time $t$, $k$ and $n$ are empirical parameters and $h$ is the temporal water storage.

### Integrating Field Inflows Into Sewer Network Model

EDM data indicates that storm overflows in this study site predominantly occur at SO2. As a result, this study focuses on the storm overflows at SO2. The rainfall data from the nearest Environment Agency rain gauge in a representative year – 2020 were used for storm overflow analysis. Five contributors to overflows were considered in the model: field inflows, ground infiltration, impermeable area surface runoff, groundwater inflow, and dry weather flow. The modelled inflows from the field using the simplified 1D model were added to the nearest sewer network node. As ground infiltration was difficult to localise and measure, its inflow was added at the sub-catchments near the STW and the quantity was calibrated based on the modelled and observed flow at the STW inlet and the EDM overflow frequency and duration. Groundwater inflow was added to the sewer network near the STW at a fixed rate of 0.0005 $m^3/s$. The contribution of each component was then analysed by removing each component sequentially from the model.

### NBS and SuDS Modelling

A single pond of 3 m diameter, 1 m deep and 1:3 side slope, was proposed as an NBS to capture field runoff, and a bio-retention cell that has 500 mm detention and 300 mm retention capacity was designed as a SuDS to mitigate runoff from impermeable surfaces. The pond was designed to intercept all surface runoff from the field, redirecting excess water to a nearby river to effectively mimic a full disconnection of the field area entering the sewer network. The bio-retention cell was modelled to be placed on existing permeable areas within the contributing drainage sub-catchments to treat runoff from impermeable areas and the exceeding stormwater drains to combined sewers at a flow coefficient of 0.2 mm/hr and a flow exponent of 0.5. Simulations were conducted in InfoWorks ICM using the built-in SuDS module with SuDS coverage ranging from 0% to 20% of total impermeable areas. Five years of historical rainfall data from the nearby EA rain gauge were used to evaluate the effectiveness of SuDS coverage in mitigating storm overflows. SuDS performance was also analysed under varying saturated hydraulic conductivity values for the field, reflecting the influence of ground infiltration volumes on the performance.

## Results and discussion

Figure 1(b) shows the modelled flow paths (red arrows) within the catchment. Two primary flow paths from the field were identified: one in the northeast and another in the northwest of the site. As the northwest flow path is connected to a separate storm sewer, it does not contribute to storm overflows. Figure 2 presents the modelled flow from the northeast field into the combined sewer during three rainfall events using the simplified 1D modelling approach with calibrated $k$ = 3.58 x $10^{-7}$, $n$ = 3.45, infiltration rate of 1 mm/hr and a coefficient of 0.1 at 5 s time intervals. The results demonstrate a reasonable response to all rainfall inputs. When compared to simulations from InfoWorks ICM the 1D approach also shows a good agreement ($R_t^2 \geq 0.8$). Therefore, it can be concluded that the simplified model is suitable for representing the inflows to the combined sewer from the field.

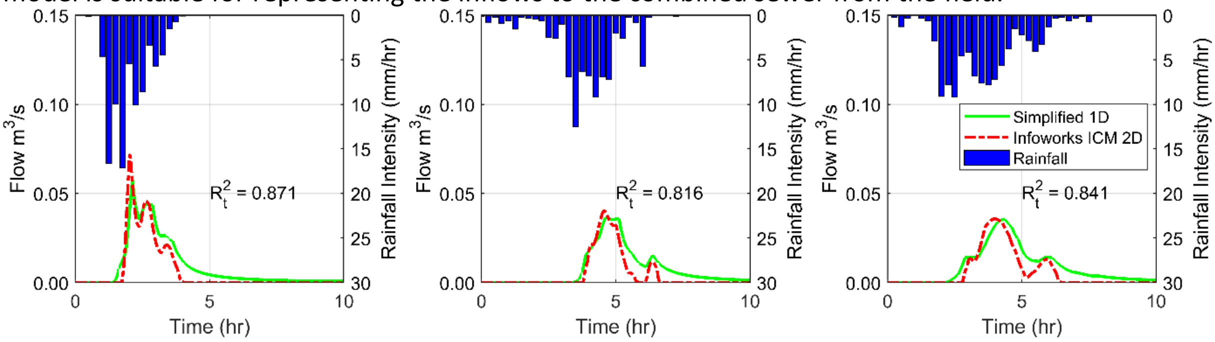


**Figure 2.** Comparison of the modelled inflows from the field to combined sewers using the 1D approach and Inforwork ICM.

The modelled overflows and durations at SO2 agree well with the EDM data, with 155 times over 1011 hours compared to the monitored 155 times over 1006 hours. Figure 3(a) and (b) show the modelled and measured flow at the STW inlet during dry and wet weather flows after calibrating the ground infiltration component. The modelled flow shows strong consistency with the measured data. Figure 3(c) highlights the contributions of different modelled components to overflows, revealing that field runoff predominantly influences overflow volume, ground infiltration affects overflow duration and surface runoff drives overflow frequency. Figure 4 illustrates the impact of the proposed NBS and SuDS on overflow reduction. Field infiltration rates/ground infiltration volumes show minimal impact on overflow frequency reduction, and SuDS coverage above 8% provides limited additional frequency reduction. While higher SuDS coverage enhances duration reduction, the effect becomes limited beyond 8%. NBS and SuDS can achieve up to a 90% reduction in overflow volume depending on the field infiltration rate, but the benefit diminishes when SuDS coverage exceeds 13%.

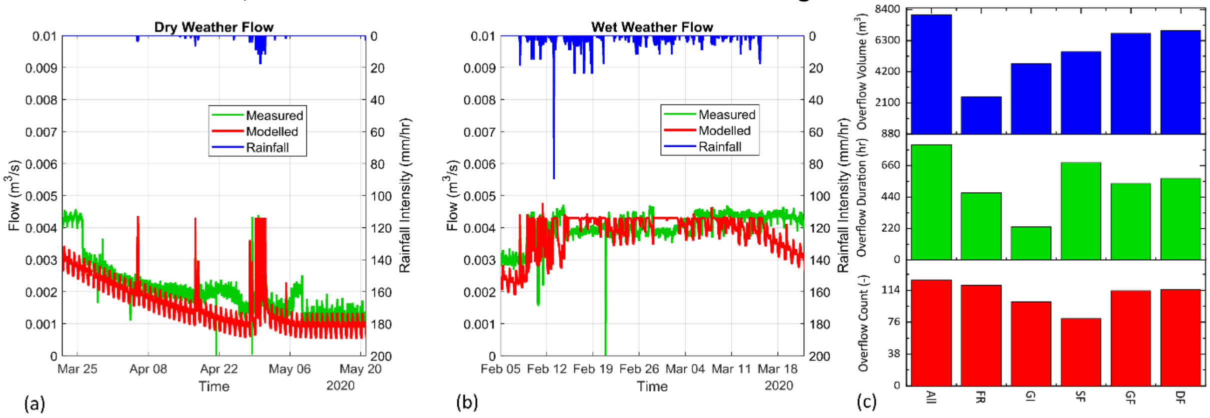


**Figure 3.** Measured and modelled flow at the STW inlet during (a) dry weather flow, (b) wet weather flow; and contribution of components to the storm overflows (c) (All: all contributing components, FR: Field Runoff removed, GI: Ground Infiltration removed, SF: Surface Runoff removed, GF: Groundwater Flow removed, DF: Dry weather Flow removed).

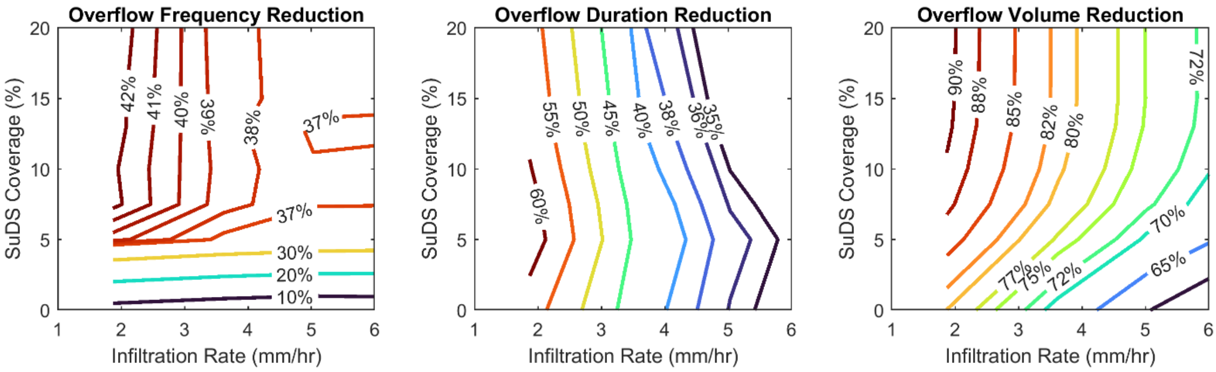


**Figure 4.** Storm overflow reduction after implementing NBS and SuDS in the catchment.

## Conclusions and future work

The simplified 1D modelling approach developed in this study effectively represents the inflows from the field to the combined sewer. Component contribution analysis to storm overflows revealed that the most effective strategy may depend on the specific reduction target (i.e. frequency, duration, or volume). For this study site, based on the modelling results, retrofitting 8% of the contributing impermeable area with SuDS, combined with a pond capturing the field runoff, can achieve average reductions of 38% in storm overflow frequency, 40% in duration, and 77% in volume. This simplified 1D approach will be applied to other sites to evaluate its suitability for modelling catchments of various characteristics. Additionally, different interventions for reducing overflows will also be investigated.

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