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Should we turn sewerage modelling on its head?

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Perspective

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Abstract

The move towards unlimited financial penalties in the UK for sewerage systems that do not operate in line with their discharge permits (and the even more extreme suggestion that there should be a financial penalty every time an overflow spills) sets a challenge to whether our existing sewerage models are accurate enough to provide certainty of avoiding those penalties. This article sets out proposed improved practice in the preparation of urban drainage models to improve their accuracy and usefulness and identifies areas where research, particularly into machine learning techniques, could deliver further improvements.

Impact statement

Modelling the performance of sewerage systems is becoming increasingly important worldwide to identify the best value responses to current impacts and future challenges of population growth and climate change. The improved practice set out in this paper could reduce the cost and improve the effectiveness of that modelling so delivering better investment decisions.

Current practice

There is a famous aphorism that "all models are wrong but some of them are useful" (Box, 1976). This was recently explored in the context of urban drainage models (Pedersen et al., 2022). Comparing the results of a model to measured data will always show a discrepancy as we are comparing inaccurately measured flows caused by uncertain rainfall on a catchment of unknown condition. However, the purpose of the model is to be useful in understanding other conditions that have not yet occurred or cannot readily be measured.

The way that a model is prepared should therefore focus on making it useful rather than necessarily accurate in individual events. In current practice, the stages in preparing a model are generally as set out by Huber et al. (2005):

1. Model build – pull together asset data and catchment data to represent the system with limited surveys to fill data gaps.
2. Short-term verification/calibration – compare the model to measured data from a short-term flow survey, covering only one season, and make corrections and adjustments.
3. (Long-term verification/calibration – compare the model to long-term measured data from treatment works, pumping stations or long-term monitors, covering multiple seasons and make corrections and adjustments.)
4. Validation/testing – compare the known performance of the system with model results from significant historical events or "design storms."

Note that verification and calibration are not generally treated as separate processes using separate data sets.

Step 3 is optional and is not always carried out.

Steps 1–3 are to check that the model is accurate and step 4 is to check that it is useful (step 4 is often called "historical verification" in the UK).

A UK Water Industry Research (UKWIR) project from 2015 questioned the reliance placed on short-term flow surveys to verify models (Osborne, 2015). Industry's current use of short-term flow data is flawed, being used to support the modellers claims of model confidence rather than to illuminate the understanding of the system performance. The UKWIR project started out with the objective of considering the use of long-term flow data instead, but this may also have similar shortcomings that the water industry must recognise.

The UKWIR project included a survey of current practice by 20 experienced UK sewerage modellers to identify the percentage of project cost spent on each of these steps. The average results are shown in Table 1.

The typical cost of short-term verification is typically 61% of the project cost. Is this delivering good value?

Table 1. Modelling cost for each stage of model preparation (Osborne, 2015)

	Modelling cost (%)	Survey cost (%)	Total cost (%)
1 Model build	22	9	30
2 Short-term verification	27	34	61
3 Long term verification	2	0	2
4 Historical verification	6	0	6
Total	57	43	100

The original WaPUG *Code of practice for the hydraulic modelling of sewer systems* (WaPUG, 2002) suggested that verification against short-term flow surveys is the first and most important step. However short-term flow surveys have some important limitations:

1. It is unlikely to record extreme or larger return period events, leading to uncertainty over extrapolating the model's results for more significant events.
2. It does not show the seasonal variation in groundwater infiltration that can be a significant factor in system performance.

Short-term flow surveys therefore need to be supplemented with long-term data and historical verification.

The more recent update of the WaPUG code as the CIWEM UDG "Code of Practice for the Hydraulic Modelling of Urban Drainage Systems" (Titterington et al., 2017) does allow for an initial validation of the model against known performance before carrying out verification against short term flow data but states: "*There is no definitive sequence of working through the stages of verification.*"

As there is a presumption that verification will be carried out using a short-term flow survey and an awareness that planning and carrying out such a survey takes a long time, it is normal to commission the flow survey at the start of the project, before the model has been built or assessed.

As the performance of the system and the model is largely unknown at this stage it is not possible to focus the flow survey on those areas with the greatest uncertainty. The survey is therefore planned to cover the whole catchment with a focus on those areas with reported performance problems.

The focus on verification against short-term flow surveys can mean that there is inadequate focus on getting the data correct for a model as, "the errors will be found during verification."

Changes to model data

The survey of current practice also identified the types and numbers of changes made to a model during verification (Table 2). The average results are shown in the table below expressed as the percentage of model nodes that were changed for asset data and the percentage of sub-catchments for contributing area data.

The results of this survey are discussed below.

Connectivity

Issues of incorrect connectivity can be identified from short-term flow survey data but are resolved by inspection of sewer asset data. They could potentially be identified by historical verification if this was carried out first.

Levels

Errors in sewer levels often have little impact on flow patterns in the sewerage system but the relative levels of sewers and ground levels have a big impact on the accuracy of the model in predicting the onset of flooding. My experience is therefore that these are more likely to be picked up by thorough historical verification than from short-term flow survey results.

However, these errors could potentially be identified earlier through close scrutiny of long sections of the sewerage system.

Table 2. Changes made to model data at each stage of model preparation (Osborne, 2015)

	Short term (%)	Long term (%)	Historical (%)
Connectivity	0.2	0.0	0.0
Levels	5.3	0.0	0.2
Capacity	5.0	0.0	0.2
Controls	0.2	0.0	0.0
Areas	38.0	0.0	3.3
Runoff factors	15.7	0.0	2.4
Infiltration	24.1	0.0	0.0
Slow response	20.9	0.1	0.1

Capacity

Major errors of sewer capacity due to incorrect pipe sizes could often be identified from inspection of sewer records and are also likely to show up during historical verification. Minor differences of capacity due to differences in roughness and sediment deposits are more readily identified in short-term verification but could be identified by more widespread use of CCTV inspection perhaps driven by modelling of likely sediment deposition.

Controls

The correct representation of control structures (including pumps) can be achieved through a thorough site survey and detailed consideration of the hydraulics of the structure. However physical survey data is often incomplete or not sufficiently accurate. Pump capacities are often re-set using short-term flow survey data as the drop tests for capacity carried out during asset surveys are not sufficiently reliable because of poor site practice. Better asset surveys would reduce the need for short-term flow surveys.

Areas and runoff

Widespread changes to contributing areas and runoff factors driven by short-term flow surveys is a concern as this is effectively force-fitting the model to runoff conditions in generally low intensity and low volume rainfall events. Adjustment of runoff factors is a particular concern without evidence of the uniqueness of the runoff surfaces in the catchment that makes the standard factors inapplicable. Changes to the runoff areas are often because a review of the existing data shows that the area has been incorrectly classified as combined or separate and that this should have been evident when the model was built and could be confirmed through site visits or impermeable area surveys.

Infiltration and slow response

In current practice, infiltration and slow response are generally picked up from short-term flow survey data as this is carried out first, but could often be identified as easily from long-term flow data and pump station operation.

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Improved practice

The discussion above also suggests that historical and long-term verification could be carried out earlier before short-term verification. So can we improve model preparation by changing the order in which we do things, by turning modelling on its head?

Also, there seems to be a step missing in our current practice – checking and improving the model data before we start verification.

So an alternative set of steps for preparing a model could be:

1. Model build – pull together asset data and catchment data to represent the system.
2. Data improvement – a detailed review of all model data to correct errors and identify uncertainties with additional site surveys where required.
3. Validation/testing – compare the known performance of the system with model results from significant historical events or "design storms."
4. Long-term verification/calibration – compare the model to long-term measured data from treatment works, pumping stations or long-term monitors and make corrections and adjustments.
5. Plan short term flow survey to address uncertainties.
6. Short-term verification/calibration – compare the model to measured data from a short-term flow survey and make corrections and adjustments.
7. Validation/testing – compare the known performance of the system with model results from significant historical events or "design storms."

The potential for each of these steps to improve each aspect of the model is shown in Table 3. This was assessed at a workshop of 60 experienced sewerage modellers.

Estimates for the cost of each step are shown in Figure 1. The data improvement step is in addition to the current model build step. The short-term flow survey can be focussed on those areas where there is still uncertainty and so would be cheaper.

Table 3. Potential improvements at each stage of model preparation (Osborne, 2015)

	2	3	4	6
Connectivity	√	√	√	√
Levels	√√	√√	√	√
Major capacity issues	√√	√√	√	√
Minor capacity issues	√	√	√√	√√
Controls	√√	√√	√√	√√
Areas	√√	√	√√	√√
Runoff factors	√√	√	√	√
Foul flow	√√		√√	√
Infiltration			√√	√
Slow response			√√	√

There are challenges in adopting a new approach.

1. Checking asset data is boring and not as much fun as verification.
2. Some water companies allocate data quality scores with asset survey data as highest quality and expert judgement as the lowest. I assume because survey teams are believed to be infallible beings who never make mistakes.
3. Short-term flow surveys are seen as delivering greater confidence than they really deliver.

The future

A few things have changed in the years since the UKWIR report was produced and set out these ideas and the pace of change is getting faster. This section sets out some potential future changes and the research needed to allow them to happen.

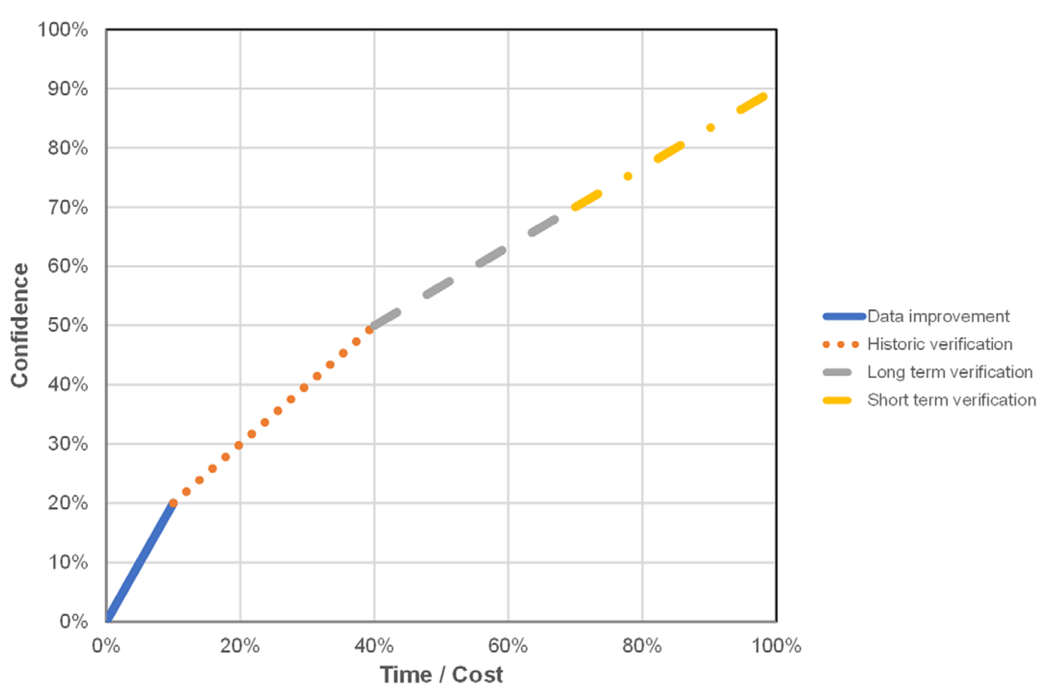

Figure 1. Cost of improving confidence for each stage of model preparation (Osborne, 2015).

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GIS data sources

One of the big uncertainties of models is the estimation of how much of the impermeable surface in each sub-catchment contributes to each drainage system. This has traditionally been based on inspection of system data to identify separate surface water sewers. However, this may not identify Sustainable Drainage Systems including soakaways.

The increasing amounts of open GIS data can bring in extra components to this analysis. Matching soil type, age of development, system type, ground slope, and so forth can give a more reliable estimate of contributing areas. The process could be made quicker and more consistent using machine learning to learn from the classification of test catchments and apply this to new catchments with varied characteristics.

This will require research on how to combine data sets of different ages, pattern recognition of map features and potentially flow data to provide robust algorithms for classification.

Correction of asset data

Modelling software has an increasing capability to use automated scripting to check and correct data. This can take much of the drudgery out of the step to check and improve model data. Scripting based on expert knowledge can look for unexpected changes in sewer gradient, diameter, material and errors in connectivity.

There is the potential to improve on this even more using machine learning to learn from modellers what corrections to make to a model. The rules would be derived from past practice and embedded into algorithms that can make the correct change when there is confidence in the issue or flag for user intervention when the required change is uncertain.

Research is needed into how to derive and apply machine learning algorithms when there is so much uncertainty in the appropriate action.

Sewer condition classification

There are already tools to use image recognition to rapidly classify sewer pipe structural defects from CCTV images. These are still not widely used and more research is needed to demonstrate their reliability and increase their use. This could also be extended to assessing no defect factors such as sediment depths and effective pipe roughness to assist modellers to move away from the use of generic default values.

Cloud computing

There is an increasing move to have model data and models in the cloud with Software As A Service to run the models. Bring this together with machine learning and with the right checks and data access agreements the data improvement algorithms can learn good practice from modellers all over the world. They could deliver better models than any individual modeller could.

Conclusions

Current practice in preparing urban drainage model focusses on them accurately reproducing measured conditions in a few events rather than on ensuring that they are useful to predict conditions in a wide range of unmeasured events.

The modified approach set out here could improve the usefulness of models and potentially save money and time in their preparation.

Future developments of automation and machine learning could give even greater cost and time savings and improved consistency and usefulness of models.

This would free modellers from the drudgery of preparing models to have more time for the important tasks of understanding and solving the problems with the sewerage systems that the models illuminate.

Open peer review. To view the open peer review materials for this article, please visit http://doi.org/10.1017/wat.2023.8.

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