Water quality modelling - Simpol, Simon & InfoWorks

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OBJECTIVES

Earth Tech has recently been involved in UPM modelling studies for several different clients that have different policies on their preferred software for modelling. We have therefore been using and comparing a variety of different software tools. This has taught us a lot about the UPM procedures and about the different software tools. The objectives of this paper are:

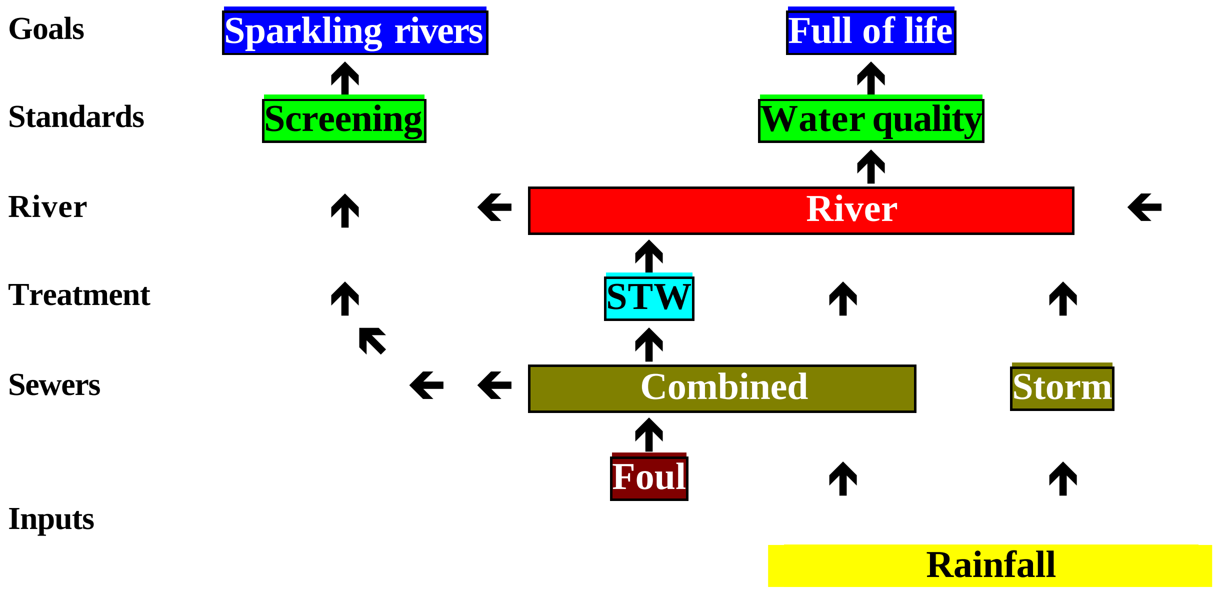
- To give some guidance on the selection of UPM tools.
- To identify some pitfalls in the use of UPM tools.
- To suggest some improvements to the capabilities of UPM tools.

THE UPM METHODOLOGY

Two key components of the UPM philosophy are:

- The goal is to safeguard river quality. We therefore need to set standards for the quality of water in the rivers and assess compliance with these standards.
- To assess performance against the standards we need to define the wastewater system as including the sewerage system, the treatment works, the receiving water and all other inputs into the receiving water. Assessment of the system requires an integrated assessment of all of these.

The components that we need to consider in the UPM methodology are shown in the diagram below.



Each of the components of rainfall, foul flow, sewers, treatment works and river needs to be represented by some form of model and there are often a variety of models of different complexities available. This paper concentrates on the representation of the river, the discharges into it and the processes that occur in it.

REQUIREMENTS OF A RIVER IMPACT ASSESSMENT TOOL

The function of the river model is to indicate the concentrations of ammonia and DO in the river due to the pollutant inputs from the rest of the system and compare these to the standards.

A full representation would take into account mixing, travel times, pollutant decay, re-aeration, photosynthesis and respiration, erosion and deposition of sediment. In practice we ignore or simplify some of these.

A full representation would also need to extend upstream to significant pollutant inputs and downstream to the lowest point of DO. A common simplification would be to model only a restricted length of the river with assumed upstream and downstream boundary conditions (critical reaches).

We can set out three criteria for what makes a good model and a wish list of some additional features.

- Allows for appropriate representation of all necessary inputs
- Correctly considers the pollutant mechanisms for (DO and NH4)
- Easy to use
    - Fast
    - Gives results that relate to the standards
    - Good documentation
- Continuous simulation as an option
- Storage assessment as an option

In this paper we consider a range of simple to medium complexity river modelling tools and consider what these requirements mean in practice and how the tools meet them.

Inputs

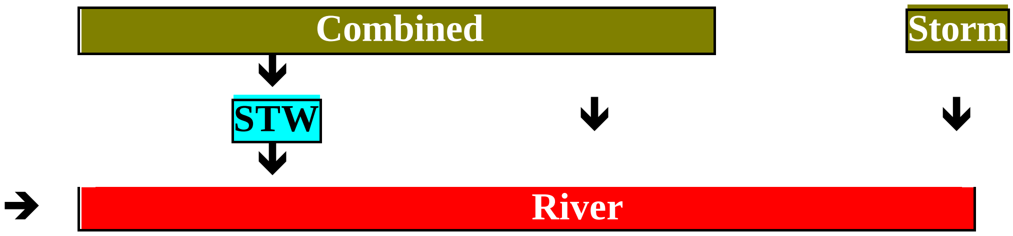
There are three ways in which we can represent inputs to the system.

1 As a fixed value (or a fixed repeating pattern).

2 As a random value drawn from a statistical distribution defined by mean and standard deviation. This would be appropriate where the values did have a significant variation but where we were unable to calculate that variation with any form of model.

3 As values produced from some form of model of the system that produces the input (such as an InfoWorks model of the sewerage system.)

We may use a different method to represent the flow input and the pollutants associated with that flow depending on how much information we have. The required inputs to the river model are summarised in the following diagram.



The upstream river boundary is normally represented by a random selection from a statistical distribution for both flow and pollution. However it is possible to model the flow using a rainfall runoff model. A model representation of the pollution concentration is also possible but this would require a complex river model and is beyond the scope of this paper.

The input from CSOs from the combined sewerage system would normally be derived from a detailed sewer model including pollutants. There is a simpler option of using the model to represent flows and using fixed or random values of pollutant concentration but this is rarely used.

The input from the sewage treatment works is best represented by modelled flows produced from the sewerage model but using random values for pollution from a statistical distribution. There is good evidence that the pollutant variation is largely random due to operation and maintenance factors.

The input from storm sewers can be represented in several ways. In can just be allowed for in the upstream river boundary and not represented separately. Alternatively it can be generated from a sewerage model. Because the pollutant load is small and is affected by un-modelled factors such as mis-connections and fuel spills it is better to use fixed or random pollutant loadings rather than trying to model them.

	Flow	**Pollution**
River	Random / model	Random
STW	Model	Random
CSOs	Model	Model
Storm	Model	Fixed / random

Pollutant mechanisms

Obviously to be of use the model must correctly represent the basic equations of what is happening in the river. These effects are:

- Mixing of inputs
- Decay of ammonia and BOD
- Re-aeration at the surface – representation of sub reaches
- Calculation of worst case situation

Basics

The decay of BOD and ammonia in the river uses up dissolved oxygen. This rate of use depends on the concentration of BOD and ammonia and so as they decay the rate of uptake decreases. Meanwhile the oxygen is replenished by re-aeration at the water surface and this rate increases as the oxygen levels in the river reduce. The result was first calculated by Streeter and Phelps and is that there is an oxygen sag downstream of the discharge. The oxygen concentration initially drops but as the BOD reduces and the re-aeration increases it starts to recover and eventually comes back to an equilibrium value.

Mixing

Ideally the model would mix each input into the river flow at the point at which it entered the river and then pass the mixed flow down to the next input. In practice most of the models lump all upstream inputs into a single entry point in the reach of interest.

Many of the models mix together the total flow and load in one-hour blocks. This is significant for the assessment against one-hour standards where the use of a one-hour timestep is likely to under-estimate the peak concentrations.

Decay of ammonia and BOD

The basic mechanisms here are to apply a decay to the BOD and to the ammonia. To allow for the oxygen uptake caused by decay of the ammonia as well as that of the BOD and to allow for the additional ammonia released during the decay of BOD. All of these are set out in the UPM manual and all of the models include them.

Re-aeration

There are several different equations for re-aeration at the surface of rivers and they have different ranges of river depth and velocity for which they are appropriate. However the equation appropriate for most UK rivers is the Churchill equation and this is used in all of the models.

None of the models allow for step changes in re-aeration at structures such as weirs, but this could be represented by an appropriate length of steep river.

Calculation of worst case

The lowest oxygen concentration occurs some distance downstream of the discharge and the calculations must be continued far enough downstream to identify this. An automatic check that this has been done would be a very valuable aid to correct use of the models.

Easy to use

Fast

To represent the full range of conditions that affect the river it is necessary to run the models for long timeseries of 10 to 15 years of rainfall. As the model also has to re-run each situation several times with different random inputs it is essential that the model runs quickly.

Gives results that relate to the standards

Analysis of the results of the models requires an assessment of the frequency and duration of exceedence of a range of threshold values of pollutant concentration. To be readily useable it is important that the models automatically calculate these values.

The UPM manual also sets out correction factors for the combined impact of low dissolved oxygen concentration and high ammonia concentrations. The models need to take this into account when assessing compliance with the standards.

However to provide an audit trail it is also important that the model also produces some more detailed results to show summary results for each event so that the mechanisms that are occurring can be checked.

Well documented

Water quality modelling of sewerage impacts is a relatively new field and many engineers have not had detailed training in the background. It is therefore essential that the models are well documented and that there are clear instructions of the steps to follow to use them.

AVAILABLE MODELS

The particular models that we have looked at are:

- Simpol 2
- Simpol 3
- Simon / Stanks
- InfoWorks CS

Simpol 2

Simpol was developed as part of the first edition of the UPM manual and was released as a software package called Simpol 2 with the second edition. It is a series of Excel spreadsheets to represent the sewer system and the rivers.

Inputs

The treatment works and upstream river boundary are both defined as random distributions for both flow and pollution. Which is a limitation for more complex studies. There is also a restriction of only one treatment works in a model.

The CSO input is represented by a very simple lumped catchment model that has to be calibrated against a more detailed model and has limitations in representing complex systems. It is not possible to bypass this to provide results from a detailed sewer model.

Storm flows are represented in a similar way to the CSO input and this may be an appropriate way to represent these.

Mechanisms

Simpol 2 includes all of the necessary mechanisms for the in-river processes. However it is necessary to accumulate the inputs from discharges further upstream into each river reach.

There is no check that the assessment continues down to the lowest point of dissolved oxygen.

The model operates at a 1-hour timestep and so can be inaccurate in assessing conditions against the 1-hour standards.

Ease of use

The model is fast and well documented and is reasonably easy to use although the requirement to calibrate against a detailed sewer model does introduce an additional step into the process.

Simpol 3

Simpol 3 is a substantial development from Simpol 2 and overcomes many of the limitations. However it is not on public release but is used by WRc for studies that they carry out.

Inputs

Simpol 3 does still include a simplified representation of the sewerage systems although it is possible to bypass this and feed in results from a detailed sewerage model.

It includes a statistical representation of treatment works and upstream river boundaries although it is also possible to represent the river boundary by a simple model representation of the rainfall land runoff.

Mechanisms

The model includes all of the required mechanisms for river processes. It also has the advantage that it can be run in continuous simulation mode so that sequences of events are correctly represented.

Ease of use

As the model is not on public release it is not possible to comment on the ease of use. However it does have tools to assess compliance with the standards.

Simon / Stanks

These two software tools were developed by MWH and have been widely used on studies for Yorkshire Water by a variety of consultants. The Stanks component deals with the inflows to the river system and the Simon component represents the river processes and carries out the assessment against the standards.

The tools are used in conjunction with a detailed model of the sewerage system in HydroWorks or InfoWorks.

Inputs

The inputs from CSOs are taken from the sewer model and are manipulated by Stanks.

The flow inputs for the treatment works can be taken from the sewer model but Stanks then allows a statistical distribution of pollutant concentration to be associated with this.

The river boundary conditions are generated as statistical distributions.

Storm water sewers can take flow from a sewer model and can use either pollutants from the same model or a statistical distribution of pollutants.

Mechanisms

The model includes all of the necessary river processes. It does not automatically check that the lowest DO concentration has been located. The model is run for individual events from a timeseries.

The model is similar to Simpol in requiring CSO discharges from upstream reaches to be accumulated and represented as discharging into reaches further downstream.

Ease of use

The model is easy to use although there are some gaps in the documentation that have led to confusion. It does report compliance with the various standards.

InfoWorks

InfoWorks has a river impact module that performs a similar function to these other models. It has similar capabilities and limitations.

Inputs

The flow inputs from CSOs and storm sewers are taken from the InfoWorks sewer model. Pollutant inputs can be either taken from the model or set as fixed values. There is no option for statistical distributions.

Flow inputs for the river boundary and the treatment works are taken from statistical distributions. There is no option to take flow values from the model and apply statistical distributions for the pollutants.

Mechanisms

The model includes all of the necessary river processes. It does not automatically check that the lowest DO concentration has been located. The model can be run for individual events from a timeseries or for continuous simulation. However continuous simulation would probably need to be run separately for summer and winter events.

In common with the other models it requires upstream CSOs to be accumulated to the downstream river reach where the assessment is to be carried out.

It is possible to adapt the use of the river impact tool to give a better representation of the mixing of different discharges. This can be done by representing the river channel as conduits in the sewerage model and then using the river impact model to assess conditions in key reaches of these channels.

Ease of use

The documentation is, as usual for InfoWorks, very thorough but takes a while to wade through to find the appropriate information.

The model is fairly fast so that continuous simulation is feasible. There is good reporting of results against the standards, although getting more detailed results to understand the results is not easy.

COMPARISON

Inputs

	River	STW	CSOs	Storm
Required	R/R or M/R	M/R	M/M	M/F or M/R
Simpol 2	R/R	R/R	Simple model	Simple model
Simpol 3	R/R	R/R	Simple or M/M	Simple or M/M
Simon	R/R	M/R	M/M	M/R or M/M
InfoWorks	R/R or M/M	R/R	M/F or M/M	M/F or M/M

Mechanisms

The mechanisms of all of the models are similar. InfoWorks has the advantage of using varying timesteps so avoiding problems of underestimating failures of the one-hour standard.

None of the models seems to make any checks that the low point of the dissolved oxygen sag has been located.

InfoWorks and Simpol 3 have the advantage of representing a more realistic mixing of the inflows into different parts of the river.

Ease of use

InfoWorks is perhaps the most flexible and complex of the models but will be familiar to someone already familiar with the InfoWorks system. Better facilities to investigate the details of the results and the mechanisms that are taking place would be an improvement.

CONCLUSIONS

None of the models is perfect and all could be improved so that they meet the needs of users.

With some improvements InfoWorks would be a very powerful tool and would integrate directly with sewerage models for integrated studies.

Simpol 3 appears to be most closely aligned with users needs, apart from not being available for them to use.