Active System Management for drainage networks: reasons to be cheerful.

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Abstract

Uptake of Active System Management (ASM) has been slow despite increasing evidence of the potential benefits that it can bring to water companies and their customers.

ASM has been in various stages of implementation for several of years, with a number of water companies performing pilot studies to assess its benefits. However, the slowness in the uptake of ASM techniques is the result of a number of 'blockers', including, limited awareness of the potential benefits, the perception that its implementation is complex and risky, the perceived cost of its implementation, and the data requirements for the system.

This paper addresses the blockers, using illustrations of available ASM techniques and examples of their use. It describes a road map explaining the development process for ASM, which can be applied to help address a range of operational problems and customer requirements. The paper presents a balanced view of the available tools for system development. Data requirements are discussed, in considering the types of observed and forecast data needed to support ASM, and the methods of enabling reliable and high quality live data feeds.

A significant advantage of ASM is its trend for using continuous and spatial rainfall records rather than using design rainfall when developing system models. Continuous rainfall records permit a better understanding of the catchment as they allow for antecedent conditions to be used as well as acknowledging that a defined return period event does not necessarily sit in isolation from other events; spatial rainfall data present a clear picture of the variability of rainfall across the catchment. ASM models are implicitly continuous simulations with each forecast run saving a state that is used to initialise subsequent forecast runs.

Some examples of the key applications and benefits of ASM are presented, including:

- Forecasting and mitigation of CSO spills;
- Forecasting and mitigation of flooding;
- Managing flows to WWTW through better use of inherent network capacity rather than costly development of new infrastructure;
- Identifying locations where system performance is suboptimal, such as blockages, sedimentation, and cross-connections.

This paper argues that actively managing wastewater networks in this way can offer significant positive operational, financial, environmental, customer service and planning outcomes.

1.0 Introduction

The juice of the carrot, the smile of the parrot
A little drop of claret - anything that rocks
Elvis and Scotty, days when I ain't spotty,
Sitting on the potty - curing smallpox

(Ian Dury - Reasons to be cheerful part 3)

In response to a near-fatal incident involving a roadie, in 1979 Ian Dury and the Blockheads sang of a large number of reasons to be cheerful, from cures for smallpox and NHS glasses, through the art of Dali and music of Shostakovich and, of relevance to drainage modellers 'sitting on the potty''. It is quite the reach to take the disco/funk of the 1979 record and compare it to the subject of Active System Management (ASM) and only limited further attempts will be made to achieve this. In the field of ASM there are reasons to be optimistic, if not cheerful, in how we look forward to implementing such systems in the coming years. These reasons include advances in computing power, increased availability of data, and, critically, the buy-in from management into the power and provision of such systems. In this paper we address where ASM has come from, what has prevented widespread uptake, advances in key input data and why there is a future in ASM for utilities.

2.0 What is ASM?

In the context of a wastewater network, Active System Management refers to the proactive way in which we can examine how the network is operating in real time and what can be done to avoid or minimise network problems, such as flooding or spills. Our industry has been largely built around the use of numerical models such as InfoWorks CS, InfoWorks ICM, and MIKE Urban and we can apply real time data (observed and forecast) to these models to understand how the system will *likely* respond in the coming hours. ASM requires that we can trust the prediction, or be aware of the likelihood of these predictions, to intervene and, critically, have the capacity to do something. It will never be possible in an urban drainage system to capture and prevent all adverse network behaviour; the uncertainty in the model accuracy, short times of concentration, the sheer number of locations where problems may be occurring and the lack of resources/equipment/man power etc. to intervene all act as blockers to the enacting of mitigation measures.

In defining ASM, we must also note what those interventions may be. The intervention will depend on the problem that is to be solved or mitigated, and may include: diverting flows in order to prevent a spill, storing or releasing flows in order to manage flow to treatment or deploying a tanker to capture an overflow. Further discussion of the interventions are outlined below in the roadmap described in Section 5.

2.1 History of ASM in the UK

The first major attempt in the UK at using Active System Management using conventional off-the-shelf software was in 2009 when Innovyze and Thames Water worked together to use FloodWorks and InfoWorks CS to develop a forecasting system for the Beckton, Crossness, Mogden and Deephams catchments in London. The end use of the system was initially aimed at, amongst other things, minimising customer complaints. But with the coming of the London 2012 Olympics, a clear driver of forecasting CSO spills into the River Lea during the games became apparent. Since then Thames Water has significantly developed its system and migrated it to ICMLive. The system now covers large parts of the Thames Water region and is regarded as an essential part of the business. Since the first FloodWorks/InfoWorks CS implementation additional systems have been developed where some are still in place and others have been mothballed.. It is useful to explore why systems don't always stay operational and what lessons can be learnt.

2.2 Active System Management Approaches

Broadly there are three categories of approach to ASM. These three categories differ in their level of complexity and the requirements of the end user:

- A correlation/regression approach (e.g. observed water level relationships);
- Hydrodynamic approach (using software such as ICMLive, MIKE Operations or Bentley's OpenFlows Flood;
- AI/Artificial Neural Networks.

2.2.1 Correlation/regression Approach

A correlation/regression approach can remove the need for a hydraulic model, and be based upon a series of water level loggers located at key sites in the catchment. These loggers have data collected at regular and frequent intervals (e.g. every two minutes). The critical aspect to this approach is to understand how the water levels at each location relate to each other and to then be able to use this information to predict what will happen downstream or in the future. An example of where this has been successfully applied is in the River Blackwater catchment in Ireland. The forecasting system picks up the water levels at six key tributaries and these are used to forecast what happens at the downstream town of Mallow.

Strengths and weaknesses

The key strengths of this approach are the run times (as typically these are almost instantaneous) and that it may be relatively easy to formulate a relationship between a number of locations. However, there are a number of weaknesses that limit the effectiveness of such an approach. Primarily relationships need to be established for every location where a forecast is required and this may not be practical. Additional weaknesses include the relative short response time available to implement an intervention and the uncertainty that may arise due to spatial variations in rainfall and local changes (blockages, outside actors such as pumping, unexpected discharges etc.)

2.2.2 Hydrodynamic Approach

The approach of taking a hydrodynamic model and applying real time data to it is well established. There a number of examples throughout the world, including various utilities in the UK, the cities of Aarhus in Denmark, Gothenburg in Sweden and Fano in Italy. A key component of the approach is that the models should be run in continuous mode, where states are saved from one run and used to initialise the next run. The result is that a model does not require 'warming up' and network conditions at the time should closely reflect reality.

Strengths and weaknesses

There are a number of benefits of the approach including the following:

- All locations in the model are forecasted, resulting in a complete understanding of the system;
- It is possible to have an alert on any or all locations in the system (even though this is not advisable);
- The models are typically well understood by those who work with them;
- Where the models are well calibrated and verified there is increased confidence in their outputs; and

- Real time system applications are available 'off the shelf' and the configuration tasks can be relatively straightforward.

The disadvantages of the approach typically revolve around the time taken to deliver a forecast run. Typical issues include:

- The simulation times of a large model may generate two types of problem:
    - The simulation time may be long enough that there is insufficient time to react to issues identified, and
    - The simulation time may only allow for a single forecast run to be carried out, where the resulting output is 'the prediction'; it is often better practice to run a series of runs using varying boundary conditions in order to create a window of uncertainty.
- In a large system alerts may be triggered at many locations. The sheer number of alerts can overwhelm the operators. Therefore, careful consideration needs to be given to how system states alerts are presented to those receiving them, and
- A model may require simplifying before it is ready for use in real time; where this simplification occurs there is a risk that accuracy may be lost, however this may be regarded as an acceptable trade-off.

2.2.3 Artificial Intelligence

Artificial Intelligence (AI) is a catch-all to describe approaches where non-deterministic or asymmetrical methods are used to predict system behaviour. There is a myriad of different methods, including Artificial Neural Networks (ANN), Gaussian Networks and machine learning. These methods train the model using historical data to predict likely outcomes.

Strengths and weaknesses

There are two principal advantages of the AI approach: speed and adaptability. Typically, the run times are very quick and this may allow for running a large ensemble size resulting in a more probabilistic outcome. The approach may also allow for the system to adapt to a wide range of situations and may not tie model parameters such as roughness and discharge coefficients to widely accepted limits. The disadvantages of the approach are the reliance on the use of appropriate training data, whether or not the AI approach has the capacity to train multiple locations, and the specialist knowledge required to implement such as system, as well as the fact that it can only model the situations that it has been trained for, so if a manual intervention takes place (pumping, closing a valve, etc) then the trained model is no longer relevant.

3.0 Blockers to Active System Management

Even though there are well established ASM systems in place, such as in Thames Water and Aarhus, uptake has been relatively slow. There are a number of legitimate reasons why wider application of ASM has not taken place. Typical blockers include:

a. **Staff resourcing.** Although many of the tasks relating to ASM can be automated it is generally required that a system be monitored to check it is running correctly and that there are no unplanned adverse network problems happening. Rather than employing a specialist it may be possible to roster staff on to the system. The advantage of this is that in times of crisis it is likely that there are multiple resources that can be utilised; the disadvantage is that there may be several weeks or longer between rostered periods and skills are lost or weaken. Resourcing the system may also be regarded as being of lesser importance as it means that staff members have to be diverted from other tasks. Overcoming issues of resourcing can be possible if appropriate senior management buy-in is achieved or if the issue is critical enough; an example of where sufficient staff resourcing has been deployed is the Flanders Environment Ministry in Belgium (VMM). VMM have devised a system where there is always at least one person supervising their system at all times and when there is a weather warning additional staff are added; the key to this happening was a director level staff member successfully arguing that the forecasting system was business critical and that the risks of either system failure or the failure of warnings to be disseminated were sufficiently high that he was able to argue for the required funds.

b. **Insufficient/inaccurate/incompatible/expensive data**. The cliché says that garbage in equals garbage out and indeed it is true that an ASM system is only as good as the data that is used to generate model predictions. Often that data is either unavailable or it is inaccurate. Where the required data is available it can be expensive to either purchase or to make it compatible with the ASM system. There are now multiple actors in the data provision market, both in relation to weather and telemetry data. In addition to the increasing number of providers resulting in decreasing costs, there are also improvements in the technology behind data capture and delivery. An important area of improvement is in how input data is filtered, checked and infilled as required before it is used as input data. Further to the checking and infilling of data many operators require a qualification of the forecast outputs and/or the input data in order to understand the confidence of the forecast. It is now standard practice to generate ‘skill scores’ when producing a forecast where observed and forecasted values are compared; these skill scores can then be used to improve further forecasts by identifying either limitations in the model performance or where additional boundary data may be required.

c. **Understanding the need/benefits.** As an ASM system can be regarded as expensive there needs to be a justification for it. It is therefore important that the potential benefits are clearly explained and that these are honestly appraised. Knowing the sorts of achievable benefits that can be obtained from a system is invaluable information at the appraisal stage of an ASM system. Preliminary studies in Japan indicated that there was the potential to save up to 14% of the pumping costs by utilising system storage in dry weather and in Malaysia there is a drive to reduce the £180,000 monthly pumping costs that a water company spends by putting in place an ASM. Amongst other things, the appraisal stage should examine both catchment response times as well as the possible interventions. When designing an ASM system, it is essential to remember the end-users; if the end-users are the operators it is prudent to have them involved from the outset in the system design. Involving operators at an early stage allows for the design of tools that will directly benefit them in the decision support workflow and is not regarded as a threat to their jobs.

d. **The IT department.** Any implementation of ASM will inevitably require a significant involvement from the IT department. Their tasks will likely include a range of things including permissions, user account management, firewall settings, procurement of hardware and software, FTP/Web data management and script development. Experience shows that it is advantageous to have the IT department involved from the outset. Experience also shows that having a dedicated and in-house point of contact is essential for ensuring a smooth process, especially during the development of the ASM system.

e. **Having got it wrong in the past – fingers burnt.** There are a number of instances where an ASM has been set up only for it to have either failed or left to gather dust. Reasons for failure include any number of problems from the above list of blockers. Failure may have been the result of incorrect design of the ASM. For example, a catchment may have been selected that, due to its size and/or the run time, leaves little or no time for operators to intervene. As a result, it may have been reasonably concluded that there was little or no benefit of the system. Other instances of ASM systems going wrong include the lack of forecast data and long delays in the delivery of the observed data. The upshot of the implementation is that the forecast results were meaningless. Overcoming previous bad experiences is not impossible, but it is difficult. Acknowledging that it went wrong and identifying improvement points is a first step to developing future ASMs.

4.0 ASM Data Requirements

Aside from a calibrated and validated/verified model that runs in good time and has good structural settings, such as management buy-in and the IT department working with the users, the most important piece of information is the boundary data used to drive the model. Typically, this will be meteorological data of some form but will likely also include data such as sea levels, structure information from ancillaries such as pumping stations and penstocks, and, where skill scoring or some form of state correction is to be used, telemetry data from sources such as loggers. Here we focus primarily on the meteorological data as experience shows that this is potentially the largest source of uncertainty and error.

For Active System Management, the main sources of meteorological data that could be used are:

1. Instantaneous rainfall radar data with a high update frequency and spatial resolution;
2. Ground truth from as many relevant weather stations and rain gauges as possible;
3. Accurate short-term forecast data with a high update frequency and spatial resolution;
4. Accurate medium range forecast data with a moderate to high update frequency and spatial resolution.

From a weather and environmental data perspective, ASM systems often use a variety of weather feeds from a range of sources. The delivery, usage, costs, diverse formats, accuracy and general interoperability challenges of these data can present serious issues for projects.

Indeed, in some cases the level of complexity and specialist knowledge currently required to successfully identify the appropriate and then integrate relevant weather data into projects or services could well render ASM projects uneconomic or technically infeasible.

What is required, therefore, is access to, ideally, a single source of the most appropriate aggregated weather data for the ASM system's needs. This source, delivered via a robust weather and environmental data ingestion platform, should deliver outputs and integrate simply with existing and new systems. To enable a minimisation of data transfer and to negate issues of data storage, the ideal solution for accessing the weather data would be to utilise an API or equivalent. While the platform should allow for observed and near real-time forecast weather and rainfall radar both now and well into the future, the ability to reforecast historical events is invaluable as this allows network performance to be analysed.

5.0 Reasons to be cheerful – it's not a 'road to nowhere'

As identified above there are a number of blockers to successfully implementing an ASM system. However, these blockers need not lead, as David Byrne sang, to a road to nowhere. Returning to Ian Dury, there are reasons to be cheerful. It is possible to develop a roadmap that can be followed resulting in a successful outcome. At the design stage there are wins that can be achieved, these include:

- Honest appraisal of the benefits through assessing the model and identifying where positive outcomes can be achieved. Model accuracy and run times combined with catchment response times are vital junctions in the roadmap.
- Engagement with all business stakeholders, especially the end-users, but also including management from the outset will allow for a system to be designed that meets the needs of but does not threaten the operators. Inviting IT and procurement to the initial meetings will also likely remove the threat of critical pathways being held up by delays relating to data and infrastructure.

- Determination of which ASM approach to use; this selection will depend on the limiting factors noted in the appraisal stage as well as other factors, including in-house skill sets and availability of applications. Where an off-the-shelf application is to be used then discussions with the various software providers (e.g. Innovyze, DHI, Bentley, Deltares etc.) or with existing users of the products is a useful step. It is the author's observations that talking to existing users often provides the most useful information as they are working where the theoretical meets the practical.
- Examining the required data and the provision of that data. Fortunately, there are now robust weather API platforms and the necessary datasets already exist. These datasets can be readily integrated into many existing software platforms.
- Defining the way that outputs are to be disseminated and the language of the alerts. Most off-the-shelf ASM systems will allow either a direct integration of outputs into an existing web or application environment. There is also a wealth of experience in multiple organisations on the subject of how alerts should be phrased, disseminated and managed.
- An important win that can be achieved is in the longer term; once the ASM is in place a number of things will happen. Confidence in the system will improve, additional benefits will be identified, a greater understanding of the system will be attained and operators will realise that there is value in the system and that it isn't a threat.

A final reason to be cheerful is that the field of ASM is rapidly growing and evolving. With that growth and evolution will almost certainly come additional actors looking to explore the potential benefits, with an impetus on finding innovative solutions, some of which will include modifications to existing tools and some of which will involve completely new tools. Those new actors and that innovation can only be a good thing as we will push the subject into new areas resulting in likely greater benefits to the end user and the customers they serve.

From the seaside round Morecambe Bay

To Covent Garden down London way

Hit me with your 'weather' stick.

(with thanks to Ian Dury)