SMART SEWER NETWORKS – LESSONS FROM OVERSEAS AND THEIR APPLICATION TO NEW ZEALAND

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ABSTRACT

Wastewater systems have traditionally been fit-and-forget. However, this is changing. Aging assets, population growth and increased environmental standards are driving the need for a new approach that integrates monitoring and modelling to actively manage wastewater systems.

Smart sewer systems monitor flows in the wastewater network and forecast changes in weather and other operating conditions to predict flows. They then activity-control flows, utilising storage in the system to improve energy efficiency and reduce overflows, delivering improved performance at less cost.

This paper sets out a vision for how wastewater systems can be actively monitored, modelled and managed. It draws on research undertaken by WSP for the UK Water Industry Research (UKWIR) and discusses the applicability of this research to wastewater networks in New Zealand.

The paper identifies that active management of sewers does not need to be complex nor expensive. Rather it is a tool that can be implemented to support management from very simple situations through to highly complex ones.

KEYWORDS

Smart Sewers, Actively Managed Sewers, Overflows

PRESENTER PROFILE

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1 INTRODUCTION

Wastewater systems have traditionally been designed to operate passively with intervention only required to address problems as and when they occur. However, long-term-pressures of increased needs and reduced budgets combine to require a new approach. Integrating the monitoring, modelling and management of wastewater systems to drive Active System Management (ASM) provides smarter sewer systems that deliver improved performance at less cost.

By Active System Management (ASM) we mean: "Improving the performance of a sewerage system by actively controlling the flow in the sewers, using either manual or automated means, based on information about the current or predicted future state of the system."

Examples of Active Control are:

- Inhibiting pumps when downstream sewers are full
- Starting pumps early when flows are increasing rapidly
- Running pumps when energy costs are low
- Retaining flow in the system rather than overflowing
- Holding back flows at high tide to reduce infiltration

The paper draws on research undertaken by WSP for the UK Water Industry Research (UKWIR).

1.1 REASONS TO CONSIDER ACTIVE SYSTEM CONTROL

Active System Management can provide significant benefits in a wide range of sewerage systems:

- **Overflow reduction** – reducing the volume and frequency of wastewater overflows during wet weather by making more efficient use of spare system capacity and storage.
- **Water quality** – managing the location and timing of overflows so they occur where they will have less impact on the environment.
- **Capital costs** – reduce capital costs by minimising scheme size.
- **Operating costs** – reduce operational costs by using operatives only when needed rather than making precautionary visits.
- **Energy reduction** – minimise the use of energy for pumping and for treatment.
- **Carbon reduction** – reduce carbon footprint of both operations and embodied carbon in new construction.
- **Service incidents** – reduce incidents due to increased awareness of the behaviour of the system and its performance.
- **Incident management** – rapid intervention to address an urgent issue (blockage, equipment failure) due to real time information gathering.

1.2 COMPARISON WITH SMART MOTORWAYS

The section of motorway between Ngauranga and the Terrace Tunnel in Wellington, New Zealand's first smart motorway, provides a useful parallel to understand the concept of active system management.

Detectors and radars count vehicles and measure their speed. The smart system calculates the rate at which the road is getting congested, factors in what's likely to happen based on traffic records that are continually updated and monitored, and then adjusts the speed limit to pace the traffic and delay queues being formed.

Data on traffic patterns is used to fine-tune the computer programme that sits behind the system to ensure it's managing the motorway effectively. The system learns over time to translate data into the optimum speed to keep traffic flowing.

Smart motorways improve safety and reduce congestion by controlling the flow of vehicles. The key is smoothing the flow of traffic and reducing sudden braking which causes a domino effect on following traffic. The system reduces driver stress and lowers carbon emissions.

2 CLASSIFICATION OF ACTIVE SYSTEM MANAGEMENT

Active system management can be classified in two ways:

- How the operator or control system knows what is happening or is going to happen in the sewerage system.
- How actions are taken to manage the system based on that knowledge.

These two characteristics provide a matrix of types of ASM as shown in Figure 1. This provides a helpful way to understand the differing levels of complexity of the systems and different strategies to move from simple to more complex systems. The figure shows examples of active system management that are discussed later.

Knowing what is happening	Fast forecast model						Copenhagen
	Fast prdictive model						
	Forecast model		London	Portsmouth			
	Predictive model	Safeswim					
	Global data analysis					South Bend	
	Local predictive						
	Local reactive				Aberdeenshire		
		Warnings	Dispatch	Operator	Local rules	Area rules	Optimiser
		Decisions and actions					

Figure 1 - Classification of ASM

The complexity and capability of the systems increases from the bottom left to the top right of the table; but the cost of developing, implementing and operating the system also increases with complexity. There is therefore no implication that a complex method is the "best" but rather that the optimum method depends on the drivers and priorities of the Water Authority.

In day-to-day operations, it is important to first know what is happening then act. However, when developing a strategy for active system management it is necessary to start with asking what management actions need to be taken and then decide what system knowledge is needed to take those actions. Therefore, the topics are discussed in that order.

2.1.1 DECISION MAKING TECHNIQUES

The decision-making techniques underpinning active management systems can be categorised as follows:

Operator Controlled Systems

- **Warning** – issue warnings for staff to take avoiding action
- **Dispatch** – send someone to take a physical action – install temporary flood defences, jet a sewer, maintain a pump etc.
- **Operator** – alert an operator to take an action such as starting a pump, closing a gate etc.

Rules based systems

- **Local rules** – the system automatically responds to local conditions based on a threshold trigger where a measurement is reaching, or is predicted to reach, a critical situation. This can then be used to change a pumping rate or alter the flow to avoid or mitigate the situation.
- **Area rules** – the system automatically uses a pre-defined matrix of decisions based on current and recent system performance to choose from a range of options. This method can be used to implement "operating regimes" where the control switches from one primary outcome to another as conditions change in the system.
- **Optimiser control** - an event-specific optimised decision using Genetic Algorithms (GAs) or other similar techniques, to enable the "best" solution for a specific event to be found by exploring many potential solutions and identifying the one that best meets the performance targets. Optimisation requires multiple runs searching for the best performance and so generally has to be implemented by combining a fast, simplified model and a forecasting system to give more lead time so that these simulations can be completed in time.

2.1.2 KNOWING WHAT IS HAPPENING

Active management systems can operate over different control horizons, ranging from reactive to short-term prediction based on current conditions, through to forecasting which predicts conditions in the sewerage system based on predictions of other conditions such as future rainfall.

The extent of control can range from local control, which based on information from a single sensor which does not take account of the state of the system elsewhere, through to area control or global control. Area control is the operation of controls in the system based on information from multiple sensors to implement actions which take account of the measurements made at these locations to maximise the use of the system. Global controls are the operation of controls in the sewer system which include consideration of the impact on the treatment works and/or the condition of the receiving waters.

Knowledge of the system generated from active system management can be categorized into the six groups as shown below, which range from simple to complex:

- **Local reactive trigger** – provides a signal when flow in the sewer reaches a defined threshold level.
- **Local predictive trigger** – provides a signal when the rate of change in flow means that it will soon reach a defined threshold level.
- **Global data analysis** – combines several reactive or predictive triggers to give an overview of what is happening throughout the sewer system.
- **Predictive model** – a detailed model of the sewer system run in real time or faster to predict what will happen in the next one or two hours based on current conditions and rates of change in the sewers.
- **Forecasting model** – a predictive model combined with rainfall forecasts to predict conditions in the sewerage system in the near future (up to 6 hours).
- **Fast model** – a predictive or forecasting model of the sewer system that runs extremely quickly so that it can be run in real time to try out many different control decisions and select the best one.

3 EXAMPLES OF USE OF ACTIVE SYSTEM MANAGEMENT

3.1 SAFESWIM (WARNING, PREDICTIVE)

Safeswim provides water quality forecasts and up-to-date information on risks to health and safety at 84 beaches and 8 freshwater locations around Auckland. It utilizes a predictive model based on past monitoring results, historical weather and other data. Real-time weather, tide and wastewater system data is fed into the model to predict current and future water quality risk, providing forecasts up to two days into the future. The forecasts are updated regularly as weather and other conditions change.

Safeswim is a joint initiative between Auckland Council, Watercare, Surf Lifesaving Northern Region and the Auckland Regional Public Health Service. Public awareness that it is sometimes unsafe to swim due to pollution has increased since the site was upgraded in November 2017. It has proved good opportunities to engage and inform the public on water quality issues.

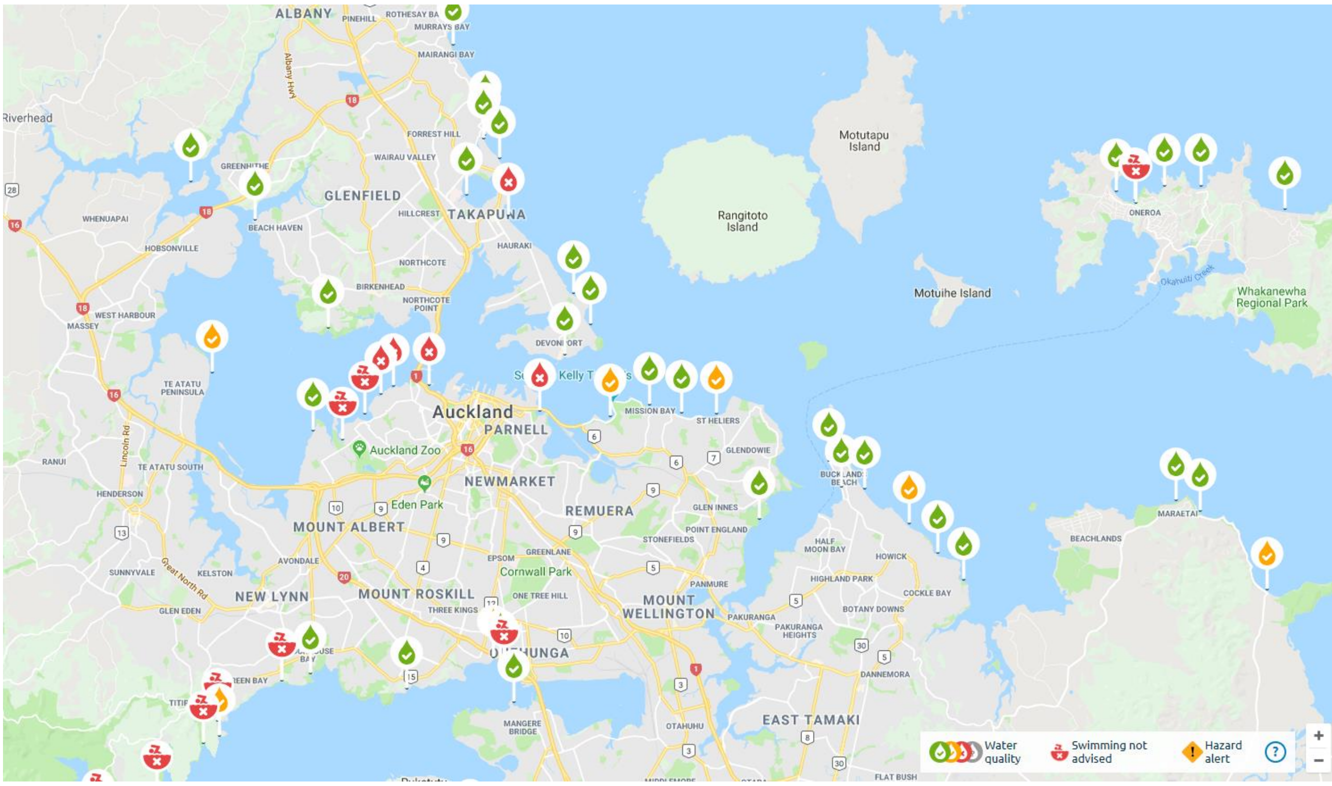

Figure 2 – Safeswim Website

3.2 THAMES WATER - LONDON (DISPATCH, FORECAST)

Thames Water set up a system using an on-line live model to cover the Hammersmith and Fulham area of west London, where there had been repeated flooding. Alerts are defined so that if flooding is predicted at key locations, or if one or more key Combined Sewer Overflows (CSOs) are predicted to spill, then staff are alerted by email. Standard rules set out what the operations staff should do for each alert. The system has helped Thames Water to proactively deal with the on-going flooding problems.

3.3 SOUTHERN WATER – PORTSMOUTH (OPERATOR, FORECAST)

The new Early Warning System draws together multiple sources of catchment information, from live data feeds to hydrologic and hydraulic models, resulting in an application which can be used to forecast the network response. The Early Warning System provides Southern Water Operations with both a view of the current state of the sewerage system and crucially, a forecast view of system performance and likely flood risk. The system links existing real time pumping station data together with radar rainfall and ground level rain gauge data to a hydraulic model to provide three hour forecasts updated every 15 minutes.

3.4 LOWER DEE VALLEY, ABERDEENSHIRE (LOCAL RULES, REACTIVE)

Lower Dee Valley is drained by a chain of pumping stations passing flow from one to another with additional local flows entering at each pumping station. The pumping stations have similar capacities and in wet weather the slight differences in flow could lead to the pumps switching on and off for short periods of time – potentially causing damage. It could also lead to occasional high levels in the pump wet wells, increasing the risk of flooding and environmental impact.

To overcome these issues, the pumping stations have two different operating modes. When the pumps at low speed can drain the wet well they operate conventionally, switching on and off levels based on wet well levels. The pumps operate at their optimum efficiency point; minimising energy consumption. When high flows are detected, based on the time taken to draw down the wet well, the pumps use variable speed drives to maintain a constant low level in the wet wells; to protect the pumps and reduce the risk of environmental impact.

3.5 SOUTH BEND INDIANA (AREA RULES, GLOBAL DATA ANALYSIS)

South Bend’s sewerage system drains to a main interceptor tunnel running along the bank of the St Joseph river with CSOs discharging to the river. CSO discharges were impacting on the river water quality.

EmNet was formed in 2004 in partnership with the City of South Bend, Ind., and the University of Notre Dame for the specific purpose of solving South Bend’s combined sewer overflow problem using advanced control systems theory and civil engineering.

The South Bend ASM consists of electrically actuated valves that balance flows from nine drainage areas to a large interceptor sewer. The valves are automatically controlled by a distributed control scheme. Each CSO discharge has a damage cost allocated depending on the impact of the spill. The CSOs “bid” for the available downstream capacity. Damage costs and control rules are designed and optimized using an off-line model

The comprehensive real-time decision support system has reduced South Bend overflow volume by 70 percent, for less than one tenth of the original budget.

3.6 LYNETTEN CATCHMENT, COPENHAGEN (OPTIMISER CONTROL, FAST FORECAST MODEL)

ASM is used to reduce CSO spills into Copenhagen’s harbour. Data from flow depth sensors at CSOs and rainfall forecasts from radar and rain gauges are inputted into a flow model. The model is auto calibrated using the flow measurements. The model uses genetic algorithms to calculate a cost function for each overflow which is based on water sensitivity, transport capacity downstream and the capacity of the treatment plant. The system tries out multiple potential control decisions and implements the one that gives the least overall cost.

4 ENABLERS FOR ACTIVE SYSTEM MANAGEMENT

4.1 MONITORING

ASM is driven by knowledge of conditions in the wastewater system. The type and extent of the monitoring integrated into the ASM depends on the strategic objectives of the system. Monitoring may include:

- Level monitoring - this is the simplest and most reliable parameter to measure.
- Flow monitoring - particularly where the performance of the system is dominated by a fixed limit on flow, for example pumping station capacity.
- Water quality in the receiving environment.
- Rainfall - to predict future flows and levels in the system.
- Ground water levels - to help predict the magnitude of infiltration into sewers.

4.2 MODELLING

Sewerage modelling has traditionally been an event-based, ‘off-line’ task, whereby the model is configured and calibrated against historical rainfall, level and flow data. This has been useful for design purposes and longer-term planning. Models can also be used to support ASM in:

- Planning response to triggers - models can be run off-line for a range of flow and rainfall conditions to select the required actions.
- Optimising control rules - The off-line model can be used to refine those rules by analysing a wide range of conditions and refining the rules to give optimum performance.
- Calibrating models - the model can be calibrated against recorded performance data from the network, to ensure that it correctly represents the system.

On-line models, making predictions in near real-time, are starting to be used as the speed of the modelling software improves.

4.3 DATA MANAGEMENT

Increased monitoring of the wastewater system will increase the amount of data being collected. Data management issues that should be considered in the development of AMS include:

- Detection communication faults.
- Automatic analysis of incoming data to identify trends and outliers and to fill in short term gaps in data and to flag when a data source is unavailable or unreliable.
- Aggregation of data from sewer monitoring with other sources of information such as district water meters, groundwater levels, customer calls or social network traffic to provide understanding of the cause of anomalies.
- Protocols for data security and sharing of data with other entities.

5 IMPLEMENTATION

ASM does not have to be complex nor expensive – it is a tool that can be implemented to support management from very simple situations through to highly complex ones. The generic steps for implementing active system management are similar, whether it is for a local control or a global control but the level of detail and the amount of work in each step will depend on the scope and complexity of the proposed system. These steps involve:

- **Stakeholder engagement** – to agree the drivers for the project and the desired outcomes.
- **Identify points of impact** – determining where monitoring should be undertaken.
- **Identify points of control -** identifying those points in the sewerage system where control structures could be used to mitigate impacts by restricting or diverting flow. The three main types of control structure available are pumps, flow controls and adjustable weirs.
- **Develop control rules** - rules can be reactive, based on current conditions in the sewerage systems, or predictive, based on short term predictions of future conditions based on the rate of change of conditions in the system.
- **Demonstrate feasibility** - control rules should be incorporated into a simulation model of the system and their performance tested over a wide range of conditions to refine and improve the rules.
- **Install monitoring** - Once the initial concept of the control rules has been proven then monitors should be installed in the sewerage system at the identified impact points to start to collect data and further understand the system performance. Monitors may need to be moved to better monitoring conditions.
- **Analyse and understand data** – for reliability and trends.
- **Refine and confirm control rules** - based on trend analysis from the monitors.
- **Ongoing review** - after each significant event and annually to identify any long-term trends such as changes in the contributing catchment, seasonal changes in infiltration flows or changes to the sensitivity of receiving waters.

6 CONCLUSIONS

Active system management provides smarter sewer systems that deliver improved performance at less cost.

Under ASM, sewer flows are actively controlled, using either manual or automated means, based on information about the current or predicted future state of the system. ASM involves the integration of monitoring, modelling and management of wastewater systems.

ASM can be used to reduce wastewater overflows, improve water quality, reduce energy consumption and carbon footprints and to reduce costs.

Active management of sewers does not need to be complex nor expensive. Rather it is a tool that can be implemented to support management from very simple situations through to highly complex ones.

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