IS MODELLING THE CORNERSTONE OF A WASTEWATER PLANNING STUDY?

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ABSTRACT

Modelling is widely considered to be the cornerstone for wastewater planning studies. When a catchment is identified as having level of service issues it is common to default to "modelling" as the means to develop a capital investment plan (CIP). A typical programme will commence with flow monitoring, followed by model build/calibration, system performance assessment, options development and analysis and finally delivery of a CIP (or catchment management plan). Most of the costs, resources, and time are dedicated to the modelling component - but can we be confident of the outcomes, and is modelling the most efficient means to the end?

This paper considers seven recent Auckland wastewater studies retrospectively to assess the role flow monitoring, modelling, and alternative analysis tools played respectively. Opportunities to achieve cost and programme efficiencies are considered to achieve the same or greater confidence in the outcomes.

Hindsight has 20/20 vision, so hindsight is applied to the studies to assess the confidence in the outputs, and whether there was a "better" way of delivering them. The conditions that contribute materially to these findings are also discussed. The findings demonstrate that :

- Some but not all studies require modelling,
- Sometimes models that are theoretically calibrated to flow monitoring data give answers that are inconsistent with flow monitoring data,
- Flow monitoring data and asset data, not a model, is the cornerstone of understanding system performance,
- Often operations data is useful, but often operations data is also misleading especially because it is incomplete,
- The presentation of models and model findings in reports generally do not allow engineers reading a report to understand what is happening in the network and why it is happening, making it impossible for engineers to review any recommendations.

This paper presents a) some key questions for consideration to assist in the structuring of a wastewater planning study, b) appropriate checks and balances to ensure the findings of the study have a high level of confidence, and c) some basic protocols as to how model and/or network information can be presented to communicate the findings more clearly.

KEYWORDS

Modelling, Flow Monitoring, validation, calibration, decision making, confidence

1 INTRODUCTION

A system performance assessment is typically undertaken to confirm what, if any operational improvements and capital improvements need to be undertaken. These improvements will only be implemented if there is an issue to be solved. The purpose of a system performance assessment therefore is to provide us with an identification of what the issues are, how big the issues are, and hopefully some insight into why the issues are occurring.

Broadly speaking any capital improvements will be limited to issues defined as spills to the receiving environment (or stormwater system) from either CSOs, pump station overflows, or spilling manholes. The critical component therefore for system performance assessment to get right is the frequency and scale of a spill occurring.

Issue identification is commonly achieved by defaulting to a modelling study. This paper cautions the project manager from jumping to this approach, and recommends some questions for consideration before proceeding with costly and time-consuming modelling. Additionally this paper cautions against relying solely on modelling outputs when populating capital works programmes, and it provides some guidance as to what additional assessment might provide more robust answers.

2 FROM HARD REAL-WORLD INFORMATION TO ABSTRACT REPRESENTATION

Wastewater network planning typically goes through a process that looks like this :

Define study area	Hard Real-World Information
Collect asset/GIS data	
Survey as required	
Plan and implement flow survey	
Build hydrodynamic model (InfoWorks or Mouse)	Abstract Representation
Calibrate model and validate	
System performance based on calibrated model	
Optioneering	
Capital investment plan	

One of the fundamental problems with this process is that it starts with hard evidence (GIS / as builts / surveys / flow data). Each piece of information is then consolidated, interpolated, extrapolated, and massaged to provide "best fit" model to replicate a complex spatial and temporal dynamic representation of what might happen hydraulically in the real world. This model is really an abstraction, and it is this abstraction which is then used:

a) To present system performance to define issues, and;
b) To determine what capital / operational investment to make to resolve the issues.

The model is calibrated and validated, but usually to within 10% accuracy of flow or depth. This accuracy range is compounded on top of the accuracy of measuring flows which is also 10% (refer Section 3 below). The model representation is therefore somewhat removed from what is actually happening. The model is usually calibrated for the largest event measured during monitoring – often in the order of a six week to three month event. Consequently the confidence in any larger events is compromised, yet it is usually larger events that are the most important for identifying issues .

The system performance, usually presented solely in terms of model outputs, therefore defines what issues need to be addressed. Occasionally "known" problems may be commented on or shown on plans at this stage. "Known" problems usually being defined by :

- Customer complaint registers, or;
- Operations staff comments or databases.

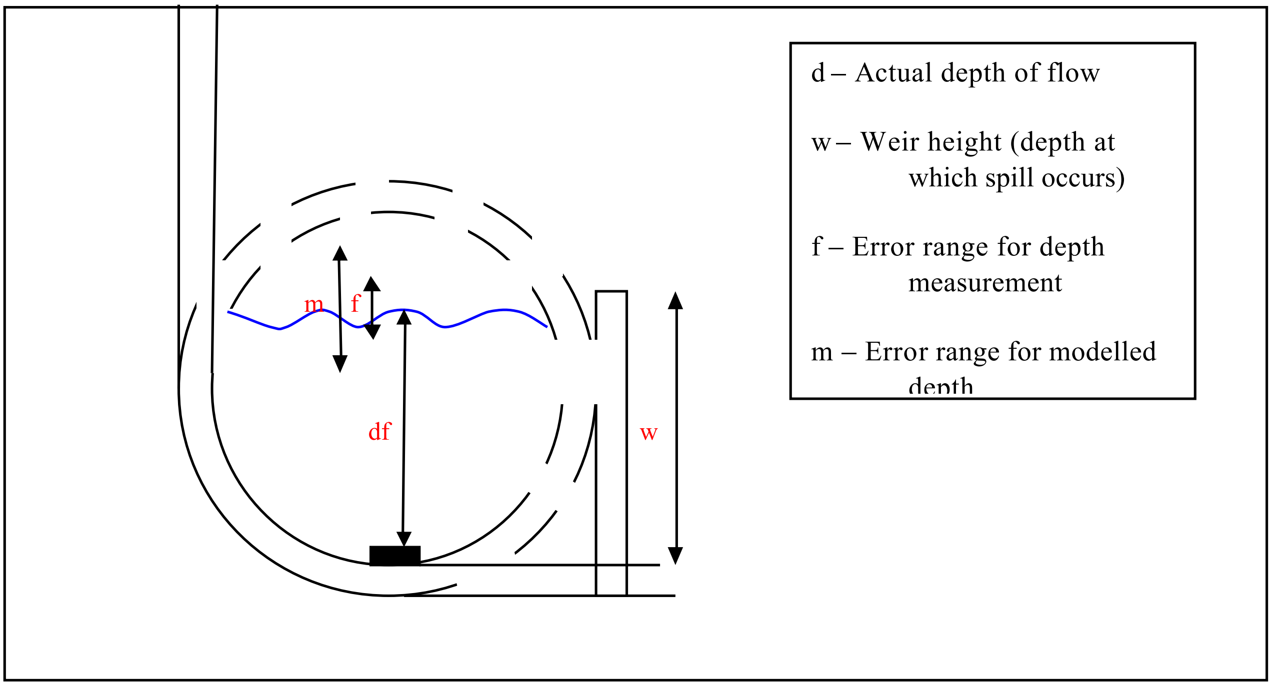
These "known" problems are usually all real and accurate, but also very incomplete. Most people do not ring a Council or a Water Utility when a manhole lid in their back yard pops and wastewater spills onto their lawn. From personal experience of questioning residents and homeowners with issues in their back yard, I have come to realize most people do not contact Council, and if they do, they only contact Council once, and then never again even if the incident is recurring, say six-monthly, or annually.

3 ERRORS AND SPILL FREQUENCY

When measuring flows in a network the data collected has an error band. This data is then used to calibrate a model, and the "fit" of the model against the collected data has an error band. These errors have the potential to accumulate and therefore provide a significant discrepancy between what really happened and what is represented in the model. Compounding on these errors is the fact that it is not possible to truly know how accurate the flow monitor was measuring flows and in addition to that not all models achieve the objective of calibration within the tolerances. This usually is commented on the calibration report, but is often not reflected on later in the study during system performance.

Some issues with monitoring and modelling errors are presented in the diagram below, representing the measurement of flow adjacent to spill weir in a CSO.

Figure Table 1: Schematic of Error Ranges for Measuring and Modelling Flow Depth Adjacent to a Weir



The above figure demonstrates the measurements and modelling errors that might be typical in a calibration process for, say, a three month event adjacent to a weir.

We see that the depth of flow "d" has an error range defined by "f" representing flow monitor error of (typically) 10%. Typical modelling specifications require 10% accuracy represented by "m". We can see here that there is no spill occurring as the actual water level (d) is below the weir level, however the flow monitor range may or may not show a spill, and the model has even greater uncertainty. The issue then with measuring and modelling spill frequency is that neither method provides 100% confidence, but modelling will always have less confidence than flow monitoring.

A spill either occurs or it doesn't. Spill frequency as a measure of system performance therefore is potentially very sensitive to the accuracy bands of the flow monitoring and the model itself.

The key issue therefore with the information we collect and model is not necessarily a representation of what is really happening, and our concept of whether there is an "issue" may be wrong.

4 INVESTIGATIONS

In this section seven studies are reviewed in relation to the value and benefit of modeling versus flow monitoring and alternative approaches.

4.1 TAMAKI NORTH

The Tamaki North Catchment is large and relatively complex with known high I&I issues and high potential growth (subdivision of existing residential lots). The catchment consists of five pump stations, a steep upper catchment, with long flat gradients at or about sea level. The solution set was predicted to be complex and include a range of generic solutions (I&I reduction, storage, upgrades, altering pump regimes and capacities) resulting in a high degree of hydraulic interaction between them. Consequently detailed flow monitoring and modelling was adopted. The study took two years from 2007 to 2009.

Five key priority areas were identified and this paper considers two :

Recently Watercare started to prepare to build multi-million dollar solutions for the following issues :

a) Spill frequency and volume from PS15 – recommendation is to construct storage
b) The spill frequency from PS53 – recommendation is to upgrade pump station and rising main

The process for analysing these issues and associated solutions is detailed below.

4.1.1 PS15

Detailed model analysis is required to resolve this issue as storage assessment is substantially about the hydrodynamic assessment of passing forward the stored flow without surcharging the downstream network. This passing forward of flow must be complete before the next rainfall falls, which is clearly dependent on long term time series analysis as it requires understanding of "typical" (or historic) occurrence of consecutive events.

Additionally optimising the design of this tank is also about evaluating a suitable spill frequency. Balancing the cost of the expenditure with the benefit achieved. This requires consideration of the receiving environment, dry and wet weather sampling, an understanding of first flush containment, and a sensitivity analysis. To ensure the appropriate size tank is built therefore requires detailed analysis for which a detailed model is most appropriate.

4.1.2 PS53

The system performance (based on detailed modelling) for Tamaki North showed the PS53 site spills eight times in an average year. On further investigation to scope the works it was decided to review the "real" data – that is the flow monitoring data, as the system performance model runs were not validated against the original flow monitoring. This demonstrated that the site spilled during a 4-6 month event, but not during a 3 month event. This equates to a spill frequency of approximately 4 times per year which makes the "issue" significantly lower priority. It was therefore decided to defer the project.

This demonstrates that it was only through assessment of the original "hard" data (flow monitoring) that a final decision on whether to invest now in improvement works was made. It also demonstrates that while detailed modelling is a valid and valuable tool, it is not in itself adequate to provide all information.

Learning : Application to study outputs – when presenting "system performance" plans it is not appropriate to only present model results. It is useful to include at least flow monitor locations, and where possible statistics about the gauged performance.

4.2 EASTERN BEACHES

The Eastern Beaches catchment is a series of relatively short and steep catchments feeding into long flat sewers that follow the waterfront including the high recreational value beaches of Mission Bay, Kohimarama, and St Helliers. The catchment has known high Inflow and Infiltration (I&I), and known high spill frequency from overflows and manholes. Identifying the cause of the spills and the subsequent solutions was anticipated to be complex and consequently detailed flow monitoring and modelling was undertaken.

The maximum ARI event available for calibration was 1 month, so while the modelling was "detailed", the accuracy of prediction when simulating a 3, 6 or 12 month event is unknown. While most of the flow monitors were removed, five overflow monitors were maintained in service during the full 2007 calendar year. Subsequently a validation assessment was undertaken with the 2007 recorded flow data evaluated against a 1 year time series simulation of the 2007 rainfall. This demonstrated that the model approximately overestimated spill volumes and frequencies by a factor of two as shown in the table below :

Table 1: Spill Frequency and volume – comparison of modelled vs gauged

	FM1	FM2	FM3	FM4	FM5
Annual Frequency (modelled / Gauged)	10 / 7	6 / 1	20 / 17	8 / 4	15 / 8
Volume (modelled / Gauged)	676m^3 / 267m^3	34m^3 / 53m^3	488m^3 / 1,019m^3	1,251m^3 / 585m^3	15,408m^3 / 3,775m^3

The above outcome is similar to the experience at the PS53 example above in that the model over-predicts spills.

This needs to be taken into consideration when making decisions about significant investment because of a modelled high spill frequency then it is clearly worth while confirming this by re-validating the spill frequency against historic flow data or monitoring the site for a six or twelve month period.

Learning : Calibrated models often do not accurately predict spill frequency and volume in part because they are calibrated with events significantly smaller than design events. Field confirmation of spill frequency must be undertaken prior to making significant investment.

4.3 OTARA

The Otara trunk sewer is known to surcharge and spill regularly leading to MCC flagging the area as a "Red Zone", meaning that no development can occur until wastewater issues are resolved. The catchment has significant growth potential as most lots are >800m2, making them eligible for subdivision. A significant number of properties are owned by Housing NZ, and it is anticipated that significant development would occur if the "Red Zone" status was removed.

Preliminary options analysis recommended storage, however the success of storage was subsequently queried due to high flow in sewers for long durations post rain, making it difficult or impossible to discharge stored wastewater prior to the next rain event occurring. Consequently a combination of localised manhole improvements, trunk capacity upgrades, and I&I control has been recommended.

Trunk modelling was used to evaluate the options, sized initially from spreadsheet analysis. The reasons this approach was deemed appropriate are as follows :

- **Localised manhole improvements :** These are relatively low cost solutions with potential for significant improvements in conveyance and consequently do not need modelling to confirm that they will provide good "cost benefit". The issues exist because of historic design issues. They are the right thing to do and engineering judgement needs to be applied to make the best improvements. Models cannot replicate the nuances of detailed design applied here.

- **Trunk Capacity Upgrades :** These are relatively straight forward upgrades and duplication of trunk systems, including future upgrading of pump capacity. The design for upgrading trunk systems is driven not so much by accuracy of models, but rather by the assumptions made in those models – I & I remains constant for the next 50 years, growth projections, future water consumption etc. Anomalies that may have a significant impact on a local network (such as an unanticipated intense development) tend to average out and be buffered in the trunk network.

  It is therefore considered acceptable and appropriate to use coarser models (including but not limited to spreadsheet assessment) when considering standard pipe upgrade solutions for trunk networks. The trunk network "zone of influence" into the local network was assessed, and was identified as being negligible. The backwater effect of trunk solutions was therefore able to be considered negligible, allowing local network issues to be assessed independently by Manukau Water.

- **Inflow and Infiltration Control :** Managing I&I is important in leaky catchments, but there is limited value in modelling this up-front for the purpose cost benefit analysis, as the success rate of I&I is dependent on the catchment conditions, and the improvement on modelled system performance will simply be in direct proportion to the assumptions made about how successful it will be. (Modelling I&I for the purposes of measuring the success of an I&I programme, however, is justified).

Learning : A detailed model is not required if the solutions are standard pipe upgrades / duplications for trunk system if there are no backwater effects.

4.4 GREY LYNN

Grey Lynn is a complex catchment. It is steep and combined with some separation. Additionally there are a high number of flooding habitable floors with contaminated with stormwater. Initially a low resolution model was built to represent the network. During the detailing of options to resolve issues it was realised that the resolution of the model was not adequate. Further, the survey data quality of CSOs in the catchment (14 No.) was identified as poor. The preliminary model did however identify that there are significant backwater effects from the trunk system in the lower parts of the catchment, and that the local network spills in part because of backing up from the trunk system. Consequently a CSO survey programme and more detailed flow monitoring of the CSOs was undertaken. This resulted in a more detailed model with a more robust understanding of the catchment and interactions between the local network, stormwater, and the trunk network.

Solutions being considered for detailed design include partial separation, full separation, some local upgrades, and significant storage and screening of overflows. Additional long term flow monitoring is now recommended to provide input to the sizing of the storage.

Learning : A detailed model is required when considering a catchment with surcharge/back-water effects, especially if storage is likely to be a solution. More detailed flow monitoring may be appropriate to understand final sizing of storage. Note, the fact that the catchment is combined and has many CSOs does not in itself mean detailed modelling is appropriate in the short to medium term.

4.5 HERNE BAY

The Herne Bay (Branch 5) catchment is known to spill regularly. Previous modelling had been undertaken, but only 3 flow monitors had been used to calibrate the 150 ha catchment, providing a low level of confidence in system performance, especially as there are 12 CSOs. The catchment is combined with pockets of completed separation. It was anticipated that separation would be the preferred means of solving the issues, however it was recognised that more data was needed to confirm :

a) The significance of the spills, and therefore the urgency of spending money in the catchment, and
b) That separation is the right solution.

Consequently 12 flow gauges and 3 rain gauges were installed for 12 weeks over the winter of 2009.

The flow data was analysed using spreadsheet tools to confirm that separation was appropriate. This analysis confirmed :

- The CSOs spill very regularly (range : every 5 days to every month)
- Time of concentration is short,
- Spills start almost immediately after rain starts, and stops almost immediately after rain stops,
- Consequently while the CSOs spill frequently, they spill relatively small volumes.

The catchment had historically been earmarked for separation, and it was initially assumed that separation would be the optimal solution. However, the flow monitoring shows the catchment responds quickly with very high flows and small volumes – which intuitively lends itself to storage as the preferred solution.

Consequently the catchment is now being modelled in detail before deciding the recommended solution and timing of implementation. The earlier spreadsheet analysis has provided a significant head start in the model build process meaning that there has been no effective loss of programme or cost by undertaking this task initially.

Learning : When dealing with a complex catchment with a high number of overflows it is important to firstly understand and monitor the performance of the network to confirm the right approach is being implemented. When considering storage it is imperative that detailed modelling is undertaken to ensure the hydrodynamics of discharges into the trunk network before the next storm are possible.

4.6 AUCKLAND'S LOWER AND UPPER CBD

Auckland's CBD was a combined system until the early 2000s when it was separated. The catchment has severe tidal inflow and infiltration, but RDII is relatively low – meaning separation was largely successful. It is subject to significant and fast development, much of which exceeds zoned planning provisions. The developments, as well as public events on or near the waterfront (rugby world cup, triathlon world championships, yachting etc) can be political and have high media coverage. Additionally managing traffic is complex and costly so working in the roads needs to be minimised, resulting in the need to thoroughly understand the catchment issues, and the need to "be ready" if any other infrastructure project is programmed so that construction is optimised and impact is minimised.

Consequently it was decided to undertake detailed flow monitoring followed by detailed modelling. Thirteen flow gauges were installed for the lower CBD and detailed modelling is currently underway. Thirty flow gauges are programmed for next year for the Upper CBD, and detailed modelling will follow.

Learning : A detailed model is required when "readiness" to deliver solutions is important. The assets must be understood thoroughly in order to be able to respond to enquiries and opportunities quickly. In Auckland's CBD the key drivers to "readiness" are : i) Growth, ii) Road opening constraints creating a need to "piggy back" on other projects, and iii) Significant public events and developments along the waterfront.

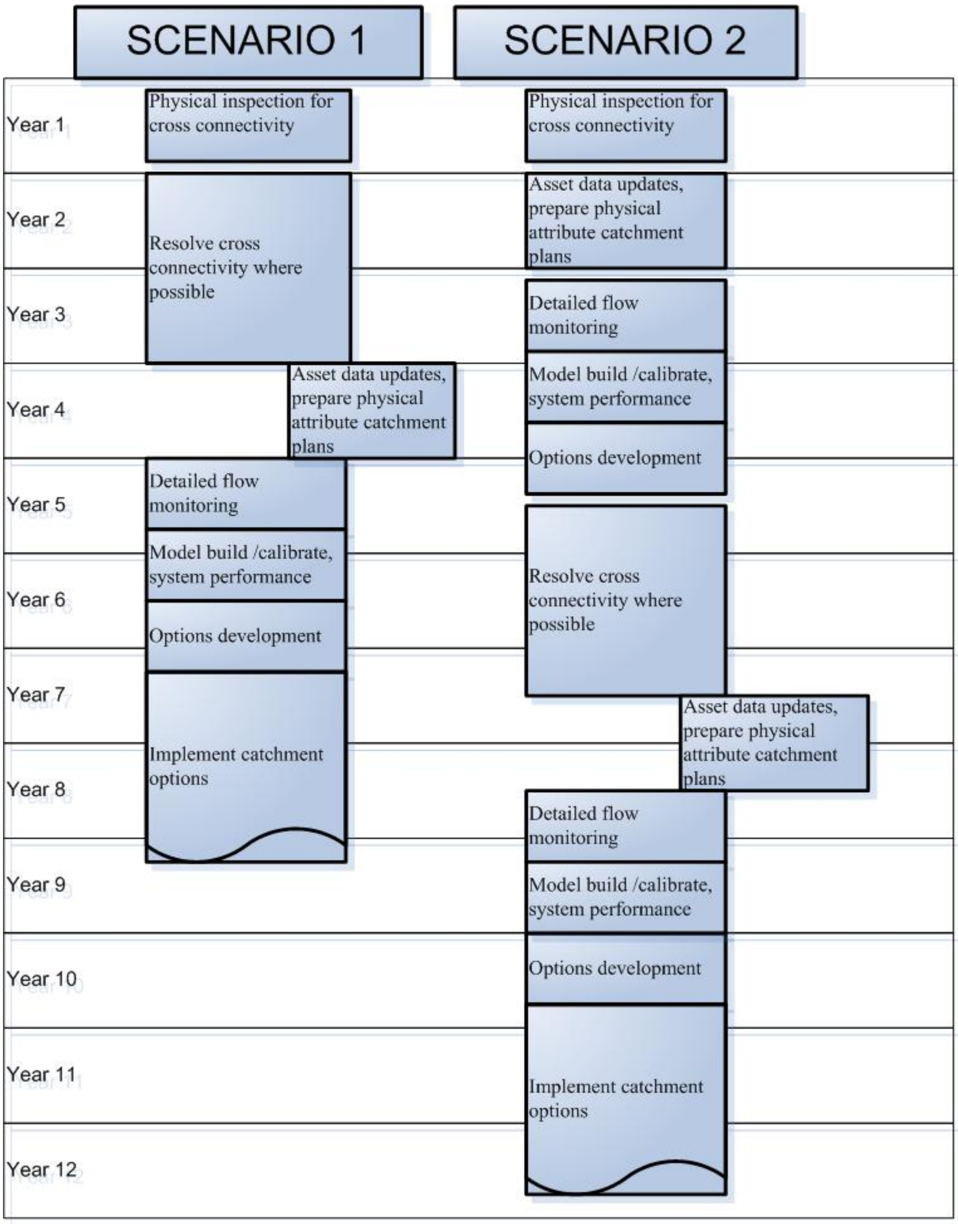
4.7 NEWMARKET

The Newmarket catchment is complex and subject to significant growth pressures. The catchment was historically combined but significant separation works have been undertaken intermittently over several decades with unmeasured success. A model with 4 flow monitors was developed in the mid 2000s, which predicted high frequency and volume flooding. A range of solutions were recommended including pipe upgrades, I&I reduction (and separation), and storage with a total cost >$20M.

On review of the study, it was identified that there were significant connectivity and cross connectivity of stormwater to wastewater which was not modelled, and with only 3 flow monitors it was difficult to have confidence in recommendations for expenditure in excess of $20M.

Consequently it was recognised that physical inspections were needed to provide a detailed understanding of connectivity / cross connectivity. Further, resolving cross connectivity issues would yield a high benefit / cost. Two scenarios were therefore foreseeable, as follows :

Figure 1: Timeline for Two Scenarios to Complete Catchment Works



This shows that embarking along the path of Scenario 1 results in real improvements commencing in the catchment at the end of Year 1, with improvements complete in Year 3. Scenario 2 results in physical work commencing in year 5 – assuming that there are no delays with procurement, variations and so on. Clearly Scenario 2 would cost substantially more, not just in terms of procurement but also in terms of skilled staff resource over a long period of time. Further, Scenario 1 is able to deliver the final part of the programme "Implement Catchment Options" from early in year 7, while Scenario 2 does not allow for this until the end of year 10.

Learning : If the catchment is subject to rapid change in infrastructure and development, and pragmatic engineering confirms that localised combined systems and known site specific cross connections are a significant issue in the catchment, then get on and undertake the basic “replumbing” works of the catchment, rather than spending years modelling and optioneering to give you the same answer. The model will be out of date again anyway if there are significant infrastructure and development changes happening.

5 CONCLUSIONS

From the investigations summarised in this paper it is clear that modelling plays an important part in undertaking catchment investigations. It is not, however, necessarily the best approach for all studies. Modelling can have significant time and cost implications with no real benefit. When issues are complex and hydrodynamic backwater effects have an impact on performance, it is important to undertake detailed modelling. A detailed model in itself is not necessarily “correct” and real data should be used to reflect on the appropriateness of the findings if detailed modelling is used. Consideration of good asset data and measured performance should, therefore be the first and final step in any study.

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REFERENCES

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