DYNAMIC MODELLING OF PRESSURE SEWERAGE SYSTEMS

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ABSTRACT

The design of pressure sewer systems in New Zealand has typically been carried out using static models; yet pump systems on the market today are 'smart systems', so why not design smarter? Dynamic modelling can optimise the design of pressure sewer systems, allowing the smart functions of the pump systems to be incorporated into the design. This is a relatively new concept in New Zealand, generally being perceived as costly and unnecessary. However, in using the right approach and understanding the hydraulic software, dynamic modelling can provide a robust, optimised design that reduces capital costs and better informs the client about how their asset will perform.

Clients and designers should be made aware of these benefits, so they can make an informed decision when undertaking these projects. This paper discusses these advantages, using the example of a modelled system for a pressure sewerage upgrade at Himatangi Beach in the Manawatu District; one of the first such models used in New Zealand.

KEYWORDS

Pressure Sewerage, Dynamic Modelling, Smart Systems, Himatangi Beach

1 HYDRAULIC DESIGN METHODS

2.1 Overview

The Water Services Association of Australia's *Pressure Sewerage Code of Australia* (WSAA, 2007) specifies the **probability method**, **rational method** and **dynamic modelling** as approved methods of hydraulic design.

The probability method and the rational method are both static models; that is, the modelled flow does not change with time. Typically, these models are developed using simple spreadsheet tools. Pipe diameters are sized for the design flow, which is expected to occur once or twice a day. The design flow is a statistical measure of the maximum flow and should not be considered as the actual maximum flow (WSAA, 2007). In New Zealand, it is these static modelling methods that have traditionally been used for modelling of pressure sewerage systems.

2.2 Probability Method

The probability method is based on predicting the number of pumps operating at any one time. The design flow is calculated using the number of pumps expected to run simultaneously and a nominal pump flow rate. An empirical relationship is used to predict the number of pumps operating at the same time. This method does not consider the number of people per household.

WSAA (2007, p.69) states that *"The probability method shall only be applied when pumps having vertical or near vertical head-discharge curves are used such as semi-positive displacement pumps e.g. progressing cavity types"*.

Designers have typically used design data from sources such as EOne Corporation (a proprietary pressure sewer pump system from the United States (USA)) when using the probability method. This has been derived from studies of existing systems in the USA. There are other sources of design data, but it is worth noting that the studies for these statistical methods were completed a number of decades ago and the data have been extrapolated to provide design tables. This method does not allow the designer to allow for various input parameters such as water consumption or more than one household connected to a pump system.

To apply the probability method, the reticulation network is divided into separate branches. The number of contributing pumps to the branch is then used to determine the design flow for the section of pipe. Iterations of pipe diameter sizing may be required if the network layout changes multiple times. With varying topography, more work is required to capture the changes in pipe and pump elevation. Thus, the probability method is easiest to apply for a gently sloping terrain where the reticulation layout is unlikely to change. When the network includes connections other than residential, these are entered as pump equivalents.

This method can be completed using simple spreadsheet tools. It has limitations since the true performance of the network cannot be easily assessed nor does it provide data on minimum and maximum flows.

Following pipe sizing, the design needs to be transferred spatially to drawings suitable for construction. Depending on the size of the network, this can be a time-consuming task.

2.3 Rational Method

The rational method is a simplified equation derived from studies conducted in the USA to determine the flow rate from a catchment. The equation assesses the catchment flow based on the population equivalent, which allows commercial and industrial flows to be included. It is important to note is that this calculation predicts that the flow contribution from each house is constant, so the same flow contribution will occur from any sample of houses.

The equation is $Q = AN+B$

Q = design flow, L/min

A = coefficient supplied by system provider

N = number of properties (= population equivalent/property occupancy rate)

B = factor nominated by system provider

The catchment is broken into separate branches, similar to the probability method.

WSAA (2007, p.69) states that *"The rational method can logically be applied when either centrifugal or semi-positive displacement pumps are used."*

2.4 Dynamic Modelling

Dynamic modelling utilises proprietary software, now available from a number of specialist software development companies. Although dynamic modelling of pressure sewers is not new, it is still uncommon: *"The application of dynamic models for designing pressure sewers has now been applied in a few cases in Australia".* (WSAA, 2007, p.69)

It is often perceived to incur unnecessary additional design cost for no benefit over that which the static models deliver. Certainly, it is true that there will always be some additional cost to dynamic modelling for the following reasons:

- Model set-up takes longer
- More experienced modellers are required
- A greater degree of verification/review is normally required
- Once the results are displayed, everyone wants to see more (as explained below).

The extent of the increased design cost is dependent on the understanding that the modellers/engineers have of the software and their ability to use it. Inexperience can lead to considerable time spent in just setting up the model to work correctly. The final bullet point above refers to the fact that dynamic modelling can provide the designer and the client with a better understanding of the system performance than static options and that, in itself, creates a desire for yet more information.

As with all engineering, before we set off on a design project, we should ask ourselves: "What is the return the client (and/or the project team) will get from this additional investment in design costs?" It may be a reduction in risk through better understanding of the system operation over a range of scenarios, or optimisation of the design. Dynamic modelling allows these systems to be optimised with far greater confidence than static models.

In using the right approach and understanding the hydraulic software, the advantages of modelling a system dynamically include:

- Better spatial representation of the network
- Assessment of the network over time (e.g. daily, weekly, monthly)
- System optimisation (e.g. reduced pipe diameters, increase flushing velocities)
- Pipe size reduction with confidence
- Improved assessment of wastewater age
- Changes in topography can be easily captured
- Ability to rapidly assess alternative design options such as growth staging
- System performance following power failure can be modelled
- Ability to assess different pump options
- Flexibility in modelling systems with different or varying flow rates.

The pump units used in pressure sewer systems are becoming more advanced in their ability to react to certain network conditions and can even be individually controlled. These are 'smart systems' using smart pumps. It is reasonable to expect, therefore, that our methods of design should advance to match this increased level of pump control sophistication, beyond the static systems that have been used to date.

One caveat to note is that it is easy to model systems beyond what is normally required and scoped. Consequently, it is good practice, before starting any project, to clearly outline what is the minimum required to deliver an optimised design that meets the design requirements set by the client or project team. The minimum required for a dynamic model are:

- Network size – large network means large savings from optimisation

- Topography
- Boundary conditions
- Catchment flows
- Pump and storage within catchment

The models are basically set up as follows. A property connection is modelled using a tank, which receives wastewater, to which a diurnal flow pattern applied. A model pump with the control philosophy matching that of the specified pumps is allowed for, drawing wastewater from the tank and pushing it into the network. The manufacturer's tank dimensions and pump characteristics are used to create these in the model. The tank levels are set at random levels at the start of the model run. Dynamic models can be set to run for a single day, a week, or longer, as required. The diurnal flow pattern can be lengthened to include seasonal changes if desired.

The models can also be used to calculate wastewater age with significant improvements over conventional methods. This is particularly useful as the model assesses diurnal patterns one can better understand risks associated with aged wastewater (i.e. those associated with septicity etc.). The model can provide various outputs; too many to list here, but typical outputs are:

- Spatial data that can be exported to AutoCAD or GIS (or vice versa)
- Thematic graphical outputs (min/max velocity, headloss, pressures, contours)
- Alternative scenarios – average day flows, peak day flows, summer flows, winter flows
- Wastewater age

2 CASE STUDY – HIMATANGI BEACH

3.1 Background

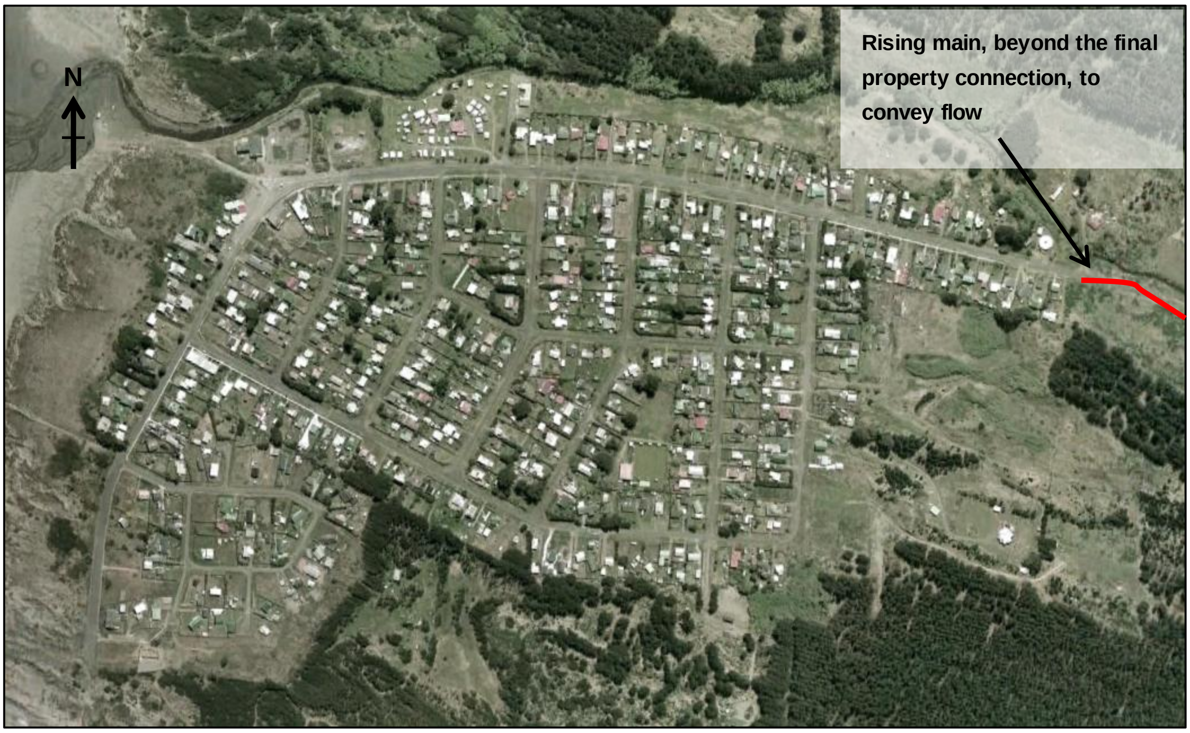
Himatangi Beach is a small community on the west coast of the North Island, under the jurisdiction of the Manawatu District Council (MDC). It is low-lying, with the ground surface sloping between 0m above sea level on the west, to 10m in the east. Although the township's usually resident winter population is around 570, it experiences a significant population influx in summer, with numbers reaching approximately 1,200.

Recently, MDC determined to establish a centralised community wastewater treatment and disposal system, to replace the existing septic tanks and wastewater disposal beds, as a means to improve public health and the groundwater environment. Based on previous studies, MDC chose to pursue a pressure sewerage system, as opposed to conventional gravity sewers and booster pumping stations, since it reduces the pipe diameters required, prevents groundwater infiltration and is easier to construct and maintain than a gravity system. On-lot grinder pump units servicing either one or two properties were chosen.

A new wastewater treatment plant (WWTP) was designed, to be built around 1.3km to the north-east of the town (see Figure 1). The rising main conveys flow from the town, discharging to the WWTP at a reduced level (RL) of 8.9m.

After tendering, a consortium of Hawkins Infrastructure, Beca Ltd, Mono Pumps and CityCare was contracted to undertake by MDC to design, construct and commission the sewerage upgrade and WWTP.

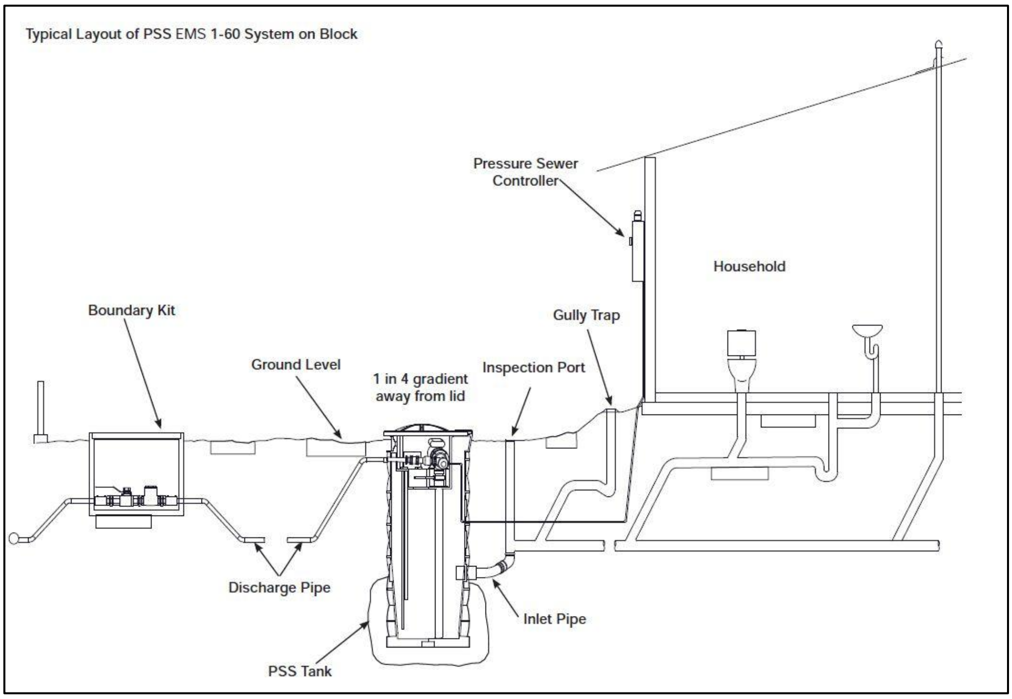
Figure 1: Aerial photo of Himatangi Beach township, showing the beach to the left (west) and the starting point of the proposed rising main shown to the right (east)



3.2 Pumping Equipment

Mono Sense EMS 1-60 Pressure Sewer Systems (PSS) were chosen as the on-lot pump and tank units for each residential property. Figure 2 shows a typical layout of the PSS on a property. From the boundary kit, the reticulation network conveys wastewater to the WWTP.

Figure 2: Typical layout of the Mono Pressure Sewer System (PSS) EMS 1-60 (Mono, 2010)



The pumps have a nominal flow rate of 1.0L/s. Figure 3 shows the pump curve, with a pressure limit of 60m head. The pumps are designed to 'trip-out' at 60m, wait a set period of time (e.g. five minutes) and then start again. If the pressure is still above 60m, the pump will stop again and wait. This 'trip-out' and re-start procedure can happen up to 10 times per hour before an alarm is triggered (when using a wait period of five minutes).

Mono Sense EMS 1-60 tanks with a volume of 900L are used to service either one or two properties (see Figure 4). These have a normal operating range of 70L and an alarm level of 330L.

In addition to the residential flow, there are a number of commercial connections with a pumped discharge flow rate of 2.0L/s. To account for the higher flows, increased storage capacity was designed for these connections, which also provides buffering during peak flows.

Figure 3: Mono Sense EMS 1-60 Pump Curve (Mono, 2010)

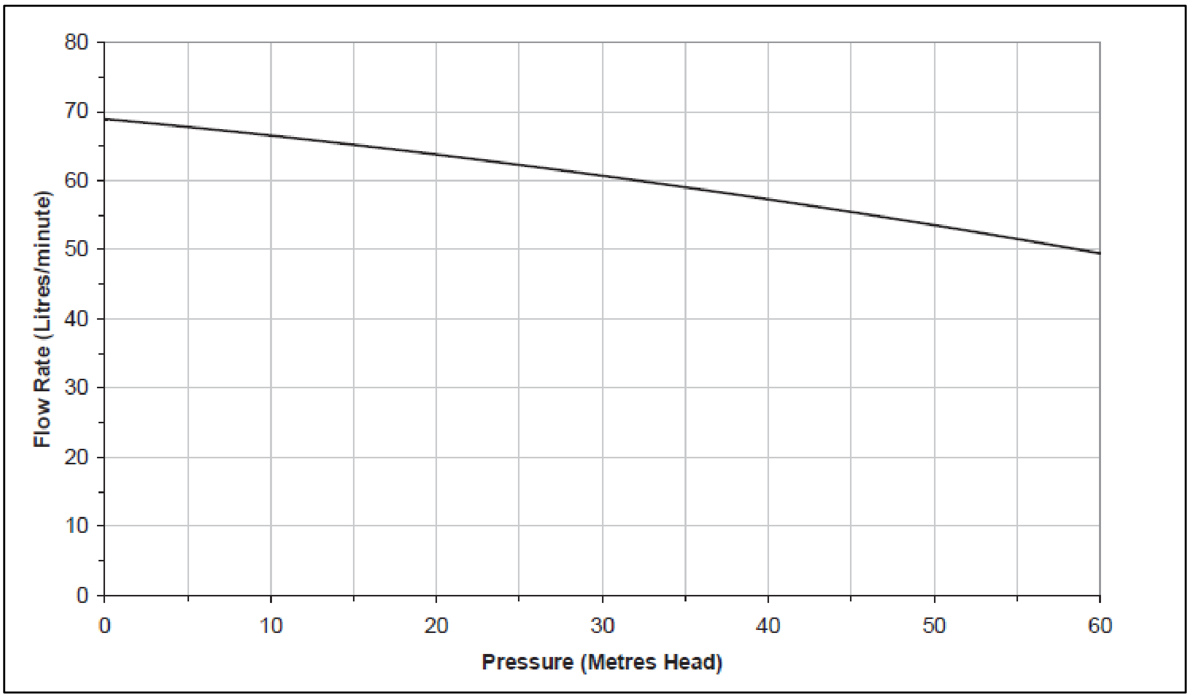
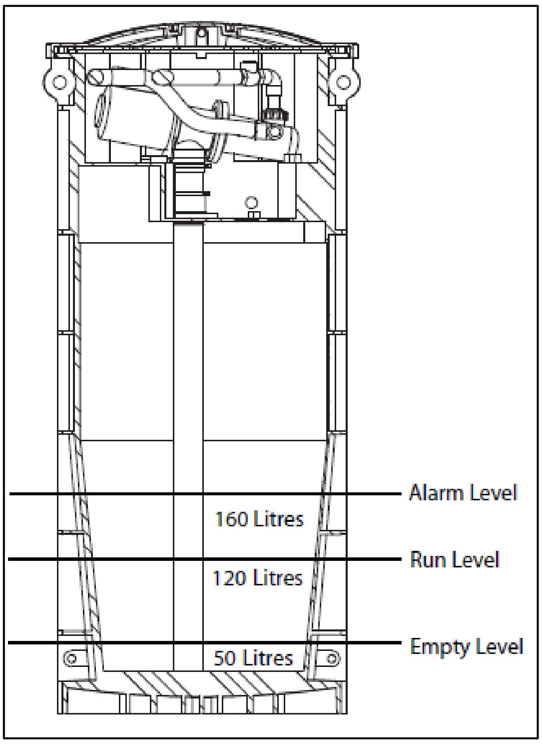


Figure 4: Section view of Mono Sense EMS 1-60 tank, with operating levels (and volumes between the levels) marked (Mono, 2010)



3.3 Hydraulic Modelling Design Criteria

The reticulation design was based on servicing around 400 properties in 2010, increasing to around 750 properties in 2041. These extra properties were added as greenfield sites and infill.

The wastewater network was designed to handle the peak day flow in 2041, servicing a summer population of five persons per property, at 200L/person/day (approx. 750m^3/d). This criterion created challenges for the static model designs, as discussed in Section 3.4.

The pressure limit of the Mono Sense EMS 1-60 pumps was 60m.

The maximum peak day velocity in each section of pipe was to be between 0.75m/s and 3.0m/s.

3.4 Static Models

During the conceptual stage of the project, the probability method was used to determine the required pipe diameters. The critical section of pipe was the rising main to the WWTP, which was both the longest section and that with the largest diameter; conveying the entire 2041 network flow. Optimising the diameter of the rising main was critical, as it had a significant impact on the pipe supply and installation costs.

To meet the design criteria, the probability method determined a rising main diameter of 250mm OD PE100 was required. The rational method produced similar results.

Based on the outputs from the static models, there were concerns that these methods of design were not suitable for this project. The high occupancy rate of 5 persons (versus 2.7 typically used), and some tanks receiving flow from two dwellings results in higher than normal inflows to the pressure sewer units. This affects the reliability of the equations: as they have statistical basis, the higher flows increase the probability of simultaneous pump operations above those that a 'typical catchment' would display. In summary, the static models did not provide the flexibility required for the design requirements for this project.

The decision to build a dynamic model was taken as it offered the following advantages:

- Flexibility to include higher inflows from dwellings
- Opportunities to optimise pipe design
- Allowed the design to consider the pump controls during design

This is one of the first applications of a dynamic model being used in New Zealand for pressure sewerage systems.

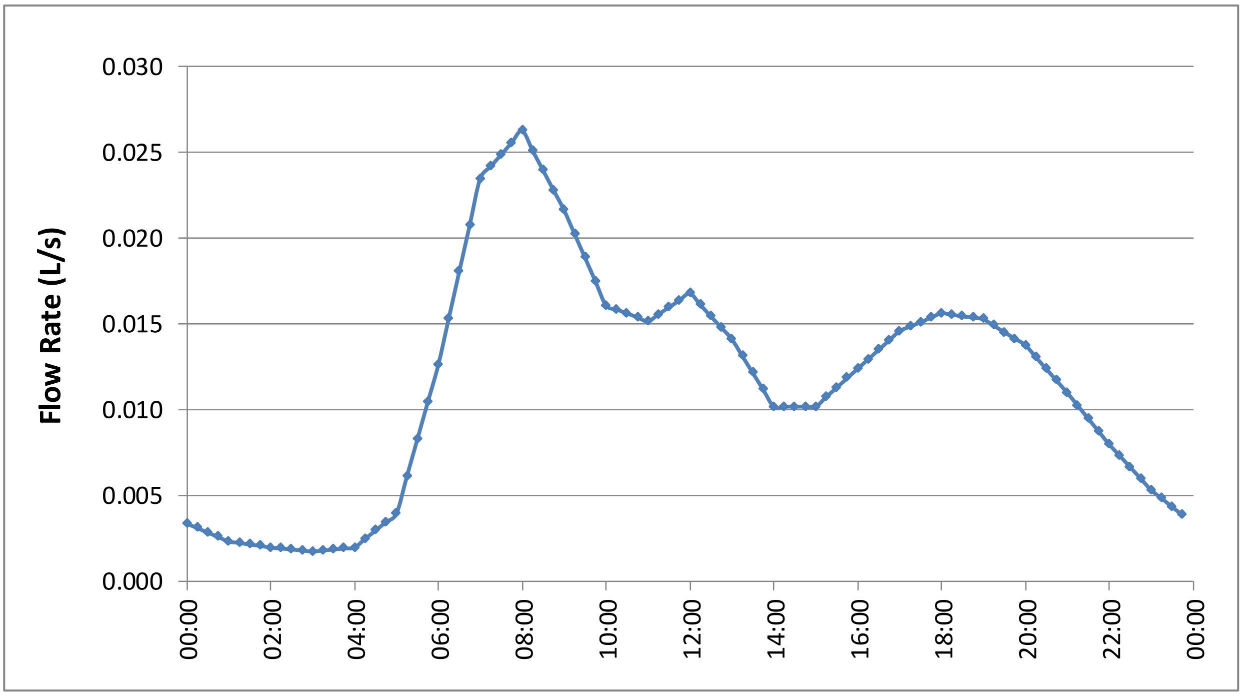
3.5 Dynamic Modelling

The proposed network was modelled using Infoworks WS (Innovyze's proprietary modelling package for distribution networks) to assess the network performance on the peak day in 2041. The requirements for the system included a high occupancy rate for each property and the inclusion of a number of commercial connections. Locations for each tank unit were provided; these were imported into the model as tanks. Each tank received flow from one or two properties, the tank's volume and dimensions were set to those supplied by Mono. Each property contributed flow to a tank and Figure 5 shows the diurnal wastewater inflow profile for a tank servicing a single property. The flow was doubled where tanks are servicing two properties.

Each tank had a pump unit; these had the same system curve of the Mono PSS EMS 1-60. The controls between the pump and tank allowed the system to operate as it would in the real world, with the pump shutting down for five minutes if operating above a discharge pressure of 60m. Unlike static models, the dynamic model has the flexibility to allow the designer to understand the individual pump system performance. Understanding what pumps 'trip' and how long pressure at the pump exceeds 60m head is key to optimising the system with confidence. An assessment of the pump performance ('trip-outs' as described in Section 3.2) was carried out to determine the maximum acceptable network pressure (effectively determining the number of pumps that could operate within the network at any one time). Utilising the ability of the pump to respond to high system pressures allowed the pipe diameters to be reduced. However, when allowing the pumps to 'trip-out', the water level in each tank was to remain below the alarm level (330L).

Modern software allows advanced pump controls, and this allows the smart pump systems coming onto the market to be modelled. This allows further optimisation with the use of these 'smarts'.

Figure 5: *Diurnal Flow Profile into the Pump Tank from a Single Property*

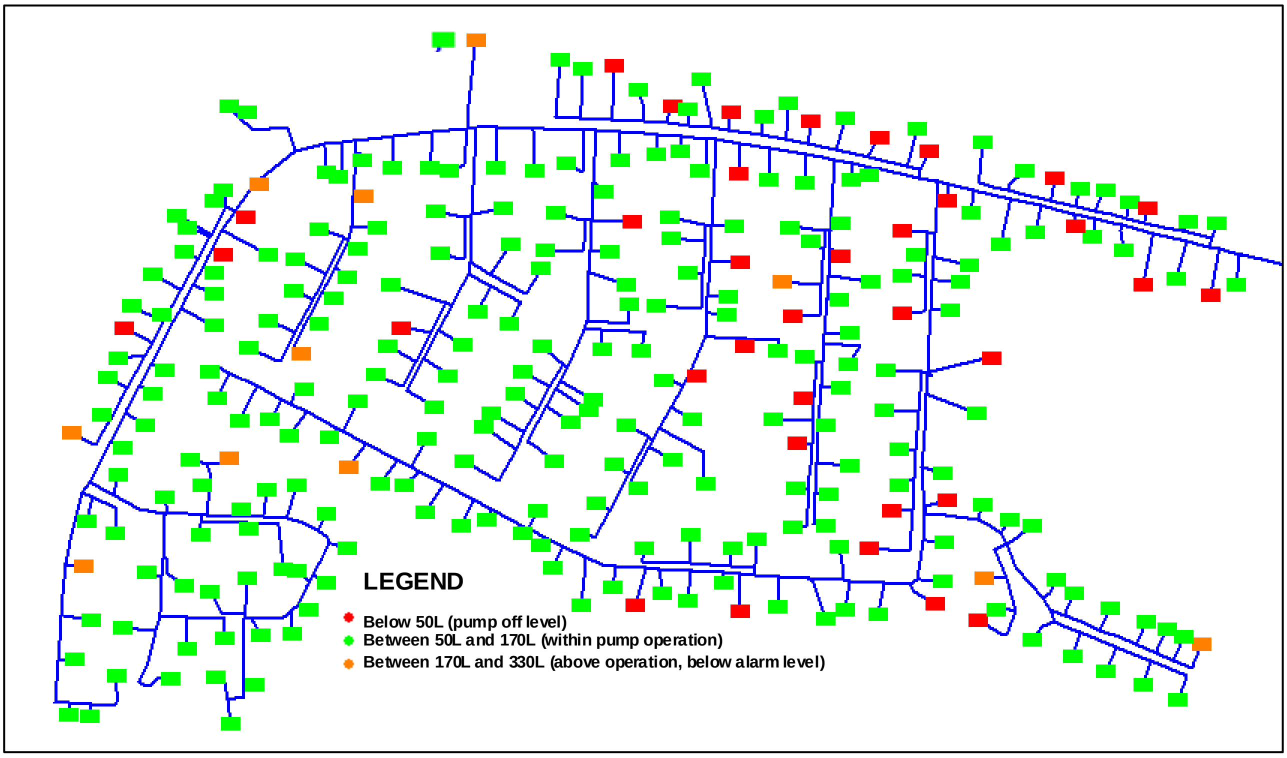


The model provides useful instantaneous outputs for the assessment of the system performance, including:

- Pumps - on/off status, flow rate
- Tanks - water level, percentage full, system pressure
- Pipes - velocity, system pressure.

These results are available spatially for any time step during the model run, and can be displayed using different themes. For example, Figure 6 shows a snapshot of modelled individual tank wastewater levels throughout the network at 8:45am; i.e. just after the morning peak wastewater inflow that was shown in Figure 5. Several tanks in Figure 6 are above the normal operating range, but below the alarm level (i.e. coloured amber in Figure 6). This occurs when the system pressures are too high, forcing their respective pump to ‘trip-out’. While the pump waits for five minutes, the tank continues to fill. If the system pressure has dropped below 60m within the five minutes, when the pump re-starts the tank will empty. If the pressure remains too high, the tank will keep filling until the pump controller ‘sees a window’ of lower pressure and allows the pump to operate. These outputs enabled discussions with the client and asset owner representative to produce a design that all parties understood.

Figure 6: Modelled wastewater levels in individual property tanks at 8:45am



Combined daily results are also available from Infoworks WS. Outputs used in this project include:

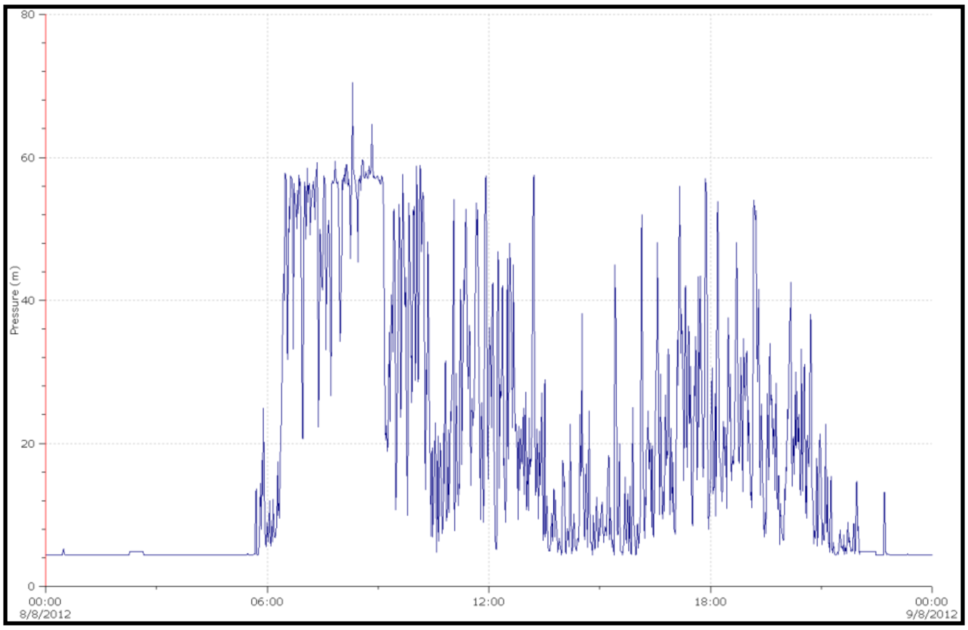
- Pumps - hours of operation, total flow pumped
- Tanks - fluctuations in water level, percentage full and system pressures
- Pipes - maximum velocity, fluctuations in velocity and system pressures

Graphs of system pressures throughout the day were used to assess whether the pipe diameters were appropriate. Pipe diameters were reduced from the pipe size obtained from the probability method until the optimal solution was reached, which still met the design criteria.

As well as optimising the capital costs of the network, it allowed the designers to assess various options quickly. The software provided excellent quality control for the project scenarios modelled and allowed outputs that clearly showed the non-modellers in the project team how the system performed. In addition to this, it allowed discussion with the asset owner representative on options for the operation of the system.

The final design was based on pumps which could be delayed from operating due to high pressures in the system, but were not allowed to trigger the high level alarm. Modelling showed that pressures above 60m occurred for only short intervals; therefore a pump that was delayed from pumping had a high probability of finding window to pump following the pump delay time. The short high pressure peak is shown in Figure 7, there are two instances of high pressure that would cause pumps to delay. This was acceptable as there was no risk of triggering an alarm.

Figure 7: Modelled system pressure over a single day, reflecting the diurnal flow variations and the non-coincident cycle of individual pump operations throughout the network



The final design, following the modelling, reduced the rising main from a 250mmOD PE100 pressure main (using the probability method) to 180mmOD – providing capital savings of approximately $80,000 solely for the rising main itself (and would have been even greater had the installation been in other than open ground, such as within a roadway). Pipe sizes were also able to be reduced within the network. This further reduced capital cost but, equally importantly, the system has been optimised for minimising retention times, as well as maintaining higher velocities for both transport of solids and minimising pipe roughness.

3 CONCLUSION

The use of dynamic modelling in the design of pressure sewer systems can offer real benefits for the design and optimisation of a network, as well as enhancing the understanding how the system will perform under various scenarios. The perception that modelling is an unnecessarily complicated and costly exercise is not justified. Beyond that possible with static models, which by their nature produce conservative designs, dynamic models can provide evidence to enable piping sizes to be reduced, with commensurate capital cost savings, more than justifying the cost of dynamic modelling. The models also provide a better understanding, for both the modeller and the end-user, of how an entire pumped system operates.

When undertaking pressure sewer projects, the client and designer should consider what design method to use based on what will provide the best outcome in overall project cost. In the case study presented, dynamic modelling was an appropriate method. The ability to account for specific client design requirements for dwelling flows was a key result in this project. More important was the reduction in pipe diameters that reduce capital costs and reduces the need for pipe flushing.

REFERENCES

Mono, (2010) 'Installation, Operation and Maintenance Instructions: EMS 1-60 Mono Sense Pressure Sewer Systems'

WSAA, (2007) '*Pressure Sewerage Code of Australia*' Water Services Association of Australia. Version 1.1