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Optimizing complex wastewater systems

Using Simcenter Flomaster to conduct dynamic water network simulations down under

Executive summary
Reliable and efficient wastewater systems are a necessity of modern city life. Dynamic modeling of the water transport process helps identify operational problems early and hence protects the environment and reduces the risk of pollution. JS Pump and Fluid System Consultants of Brisbane, Australia are specialists in hydraulic modeling of complex fluid networks and advanced control systems, providing flow assurance servicesfor a range of industries. With more than 20 years of experience with Simcenter™ Flomaster™ software, which is part of Xcelerator, the comprehensive and integrated portfolio of software and services from Siemens Digital Industries Software, JS Pump and Fluid System Consultants are now focusing on the analysis and optimization of complex wastewater systems.

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Abstract

Large wastewater systems comprise a network of pump stations connected by rising mains and gravity mains. They are designed to gather and transport domestic and industrial wastewater from the point of origin to a central wastewater treatment plant for processing. Pump stations receive inflow from connected mains and also gather inflow from the local effluent collection system. Outflow capacity is controlled by pump performance and discharge pipe capacity. Pump station storage volume is determined by the dynamic response between inflow and outflow. Depending on local topography and organic growth, a wastewater system may cover large areas of over 100 square kilometers (km^2). Excessive inflow during heavy rain events or breakdown of essential equipment may result in overflow at a pump station and must be avoided for environmental and public health reasons. It is therefore essential to identify bottlenecks during planning and design and provide additional overflow storage in strategic locations. Hydraulic modeling of complex wastewater networks is traditionally carried out in steady-state mode. However, dynamic simulations are able to predict a time-based system response that may prove important. For example, time lags resulting from filling and draining gravity mains may have a significant impact on the overall system capacity and thus require careful consideration.

The wastewater system network, a complex network serving parts of a major city, is made up of some 90 pump stations and is shown in figure 1. The system network, terminating in a central wastewater treatment plant, can be divided into four individual subsystems, all operating (hydraulically) independently from one another. The largest subsystem has been selected for this study. The hydraulic envelope is composed of some 48 interconnected pump stations and a similar number of rising and gravity mains.

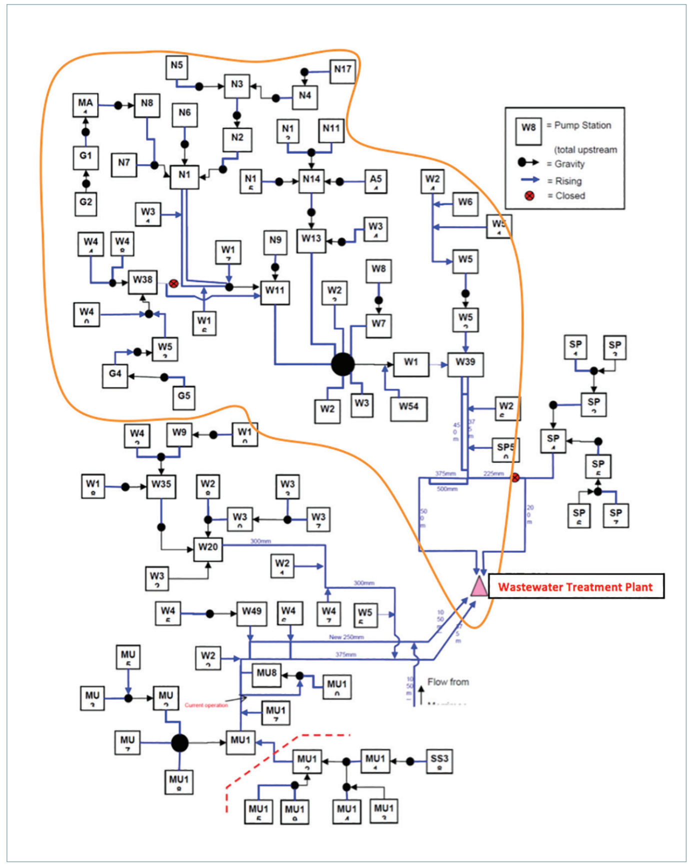


Figure 1: Complex wastewater system network.

Pump stations within this subsystem are the wet well type, each containing two electric submersible pumps. These pumps are started and stopped by water level switches, installed in a cascade type arrangement. However, the network control systems can override the level switches and provide a smart system response. For example, during a local heavy rain event, the control system identifies heavy inflow and initiates starts of downstream pumps before their normal start water levels have been triggered. This results in moving wastewater forward earlier and thus creates additional dynamic buffer volumes.

The pump station hydraulic model

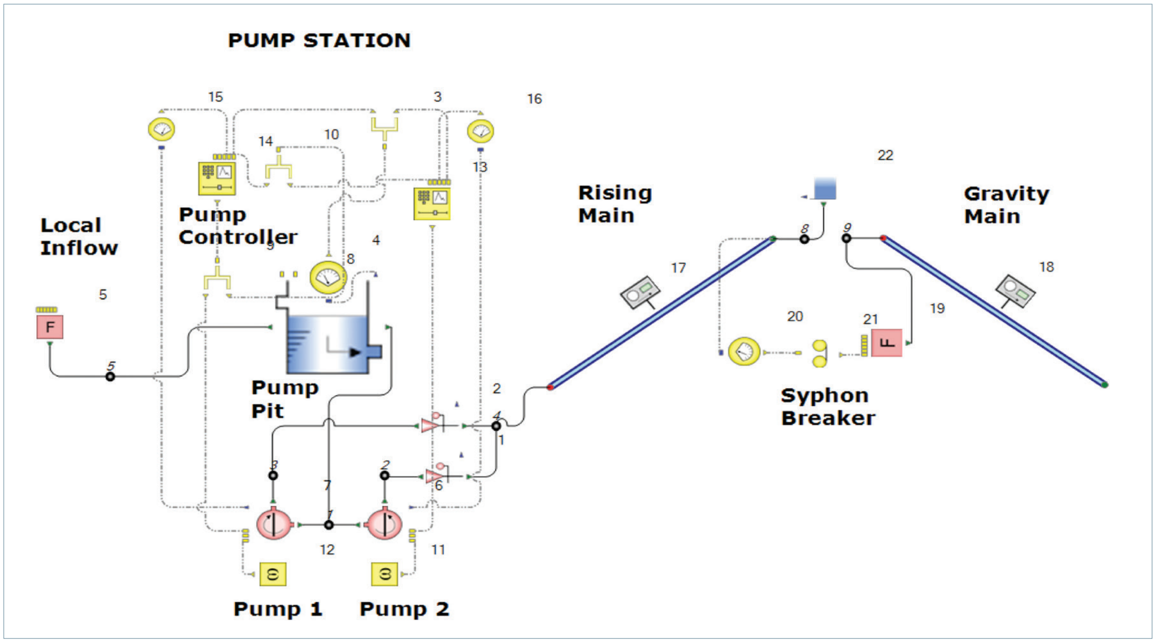


Figure 2: Simcenter Flomaster pump station hydraulic submodel.

Initially, a hydraulic submodel, including rising and gravity mains as shown in figure 2, was developed in Simcenter Flomaster to closely resemble the network pump stations. Each pump station contains a level-controlled pump pit with inlet and outlet. The pumps are connected to the pump station outlet and arranged in parallel, their discharges isolated from the rising main by nonreturn valves.

Each pump is driven by a dedicated pump logic and speed controller that is capable of advanced Programmable Logic Control (PLC) type features. Input of operational variables into the pump controller such as pump speed and pit water level are provided by gauges.

Pumps in this case are operated in start/stop control mode, based on wet pit water levels programmed into the pump logic script.

The pump station hydraulic model was then tested in isolation to ensure its functionality would meet all operational requirements, both in steady-state and transient operation. The hydraulic submodel can be easily modified for additional pumps if required.

The Simcenter Flomaster wastewater system hydraulic model functionality enables copying of component groups such as the pump station model and placing them in an arrangement closely resembling the wastewater system network schematic. The wastewater system hydraulic model shown in figure 3 is essentially made up of multiple pump station submodels. Additional rising mains and gravity mains were added to create the complete hydraulic model, now consisting of almost 1,000 components. Pumps and valves were modeled based on performance characteristics. When not available from manufacturers, performance information was based on, *Fluid Flow Systems – Second Edition* by D.S. Miller, BHRA 1990.

Rising mains were modeled as full-flowing elastic pipes. Simplified pipe profiles were incorporated to enable the generation of pressure envelope plots. Gravity mains are typically partially full (open surface) flowing pipelines. As shown in the pump station submodel, a syphon breaker was introduced to enable the transition from internal fluid flow to an open surface flow regime. A time delay was introduced to account for the duration of filling and emptying the gravity mains, depending on slope and pipeline length.

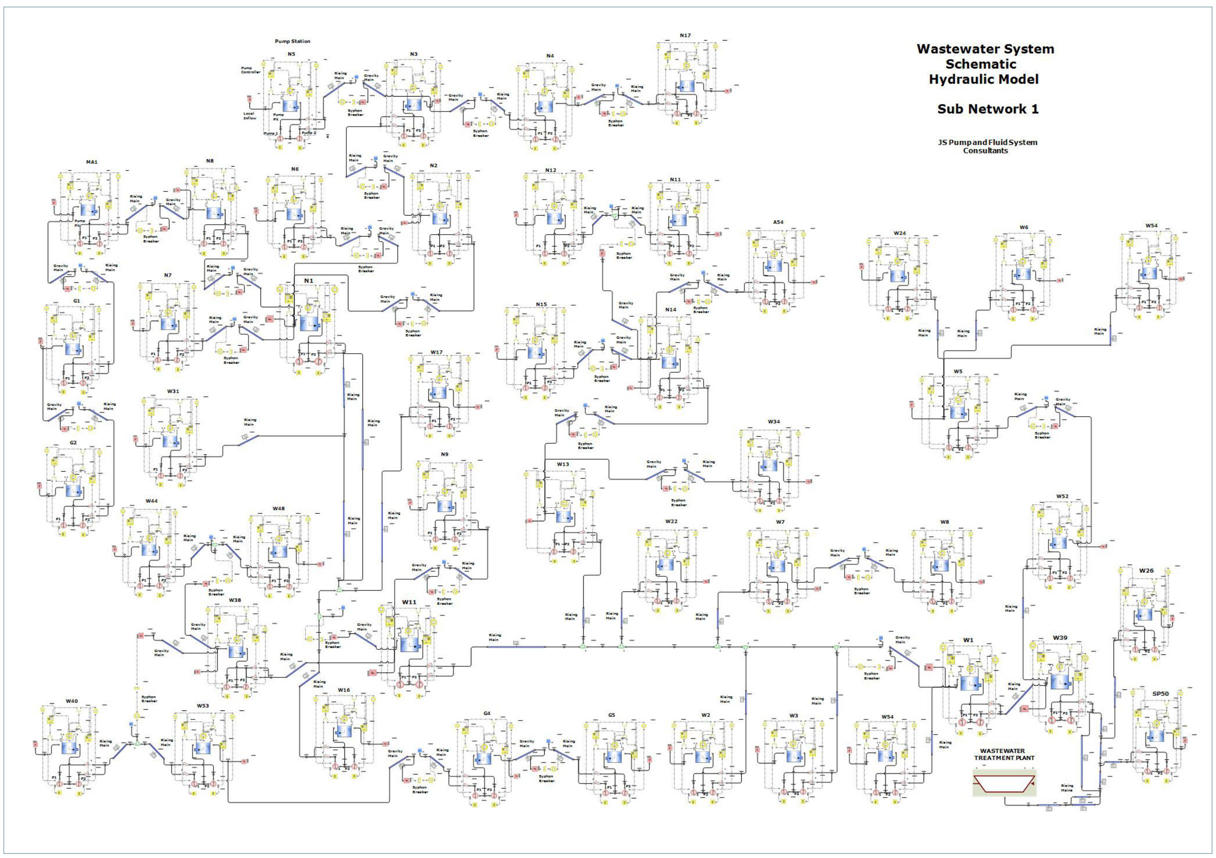


Figure 3. Wastewater system hydraulic model made up of multiple pump station submodels.

The operational simulations

Transient operational modeling enables a complete understanding by the designer/operator of how the interconnected system behaves dynamically under various inflow and pump/storage/pipeline capacity scenarios. Average dry weather flow (ADWF) and ultimate peak wet weather flow (UPWWF) events can be set up by pump station inflow versus time curves. Alternatively, time constant inflows can be tested. Pumps and valves can be disabled to model equipment breakdowns. Deterioration in pipe roughness and blockages can also be modeled to determine the impact on adjacent pump stations and whether this may lead to unintended overflow.

Although total pump discharge capacity was selected to accommodate maximum expected inflow, it is important to confirm the existing pump size/number would result in a reasonable number of pumps starts per hour. Note frequent pump starts may lead to early motor failure. Large pump motors sometimes tolerate only two starts per hour.

The ultimate peak wet weather flow simulation

The ultimate peak wet weather flow UPWWF event is considered the most challenging operating scenario a wastewater system has to cope with.

The main purpose of this simulation was to:

- Identify any overflow situation
- Determine number of pumps starts
- Identify any pressure surge (water hammer) issues
- Establish maximum dynamic system capacity
- Identify potential control system improvements

For this simulation, a duration of 2,000 seconds, it was assumed all components in the hydraulic model would be in service. A time step of 0.2s was selected, sufficient to capture transient events such as pump starts and nonreturn valve (NRV) closures. A further simulation of shorter duration was performed at a time step of 0.02 to capture critical surge pressure events. Live on-screen performance graphs were set up to visualize the simulation for particular components.

Component files were set up as follows:

- Local inflow set constant at 70 liters per second (L/s) for each pump station
- Pump pit capacities ranging from 35 cubic meters (m^3) to 1850m^3
- Pump duty ranging from 50L/s to 2,300L/s
- All pump pit levels set for an initial water level of 0.5 meters (m)

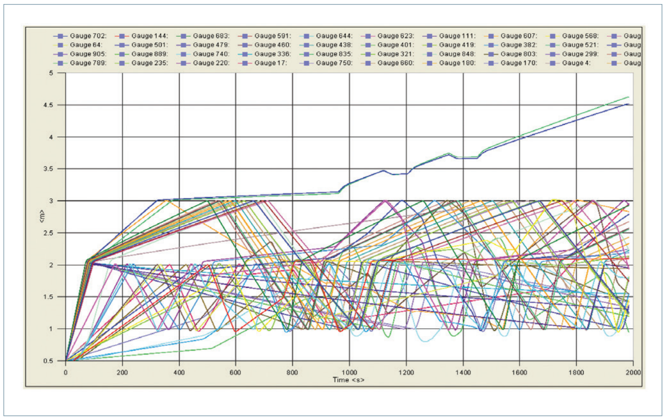
Pump start/stop logic was set as follows:

- Pump 1 start at pit level >2m
- Pump 1 stop at pit level <1m
- Pump 2 start at pit level >3m
- Pump 2 stop at pit level <1m

The result plots

During the dynamic simulation, Simcenter Flomaster is used to track some 6,000 active parameters. Result plots do not require prior selection. However, obviously unimportant parameters may be deselected in order to create smaller result files. Overlays can be produced for any combination of X-Y axis parameters. Shown below are the most significant results identified for this simulation.

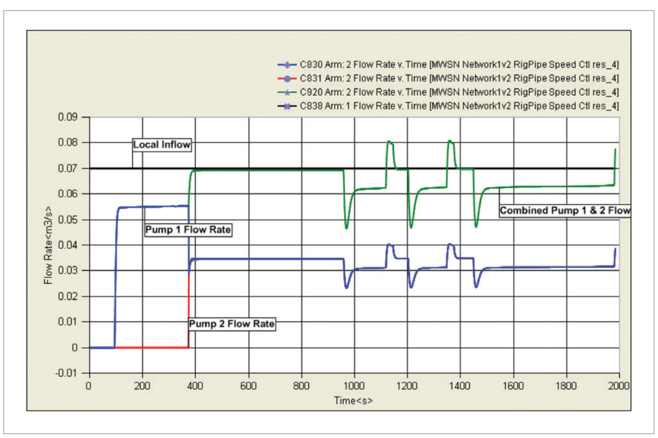
Conclusion



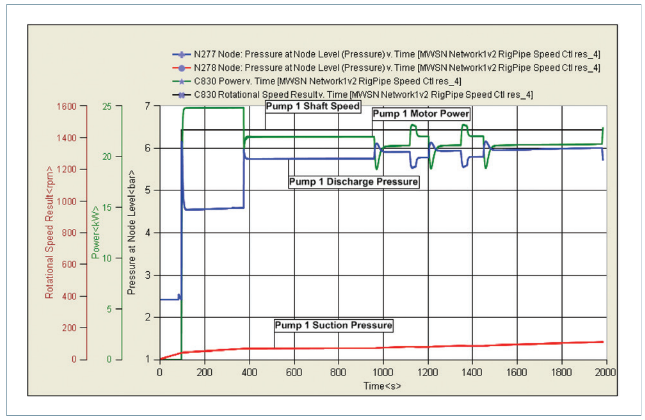
Graph 1. Overlay plot tracking pit water levels of all 48 pump stations. Pump stations W12 and SP50 are not coping with the inflow.

System overflow

Graph 1 clearly shows pump stations W12 and SP50 are not coping with inflow for the UPWWF event. This situation can be corrected by replacing the pumps with higher discharge pressure pumps. The simulation would then be rerun to ensure the problem has not passed onto the downstream pump stations.



Graph 2. Pump Station W26: component flow rates, indicating combined pump capacity in not coping with inflow, eventually leading to pump pit overflow.



Graph 3. Pump 1 in Pump station W26: power, speed, suction and discharge pressure, indicating significantly high rising main backpressure.

Pump starts

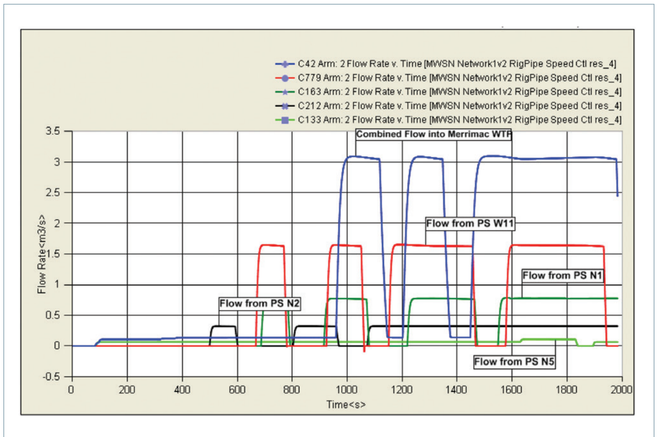
Several pump stations do not contain the optimum size and number of pumps, especially the larger pump stations near the wastewater treatment plant, which showed an unacceptably large number of starts of the duty pump, while the second pump did not start. Reducing individual pump capacity and increasing the number of pumps would overcome this problem.

Surge pressure

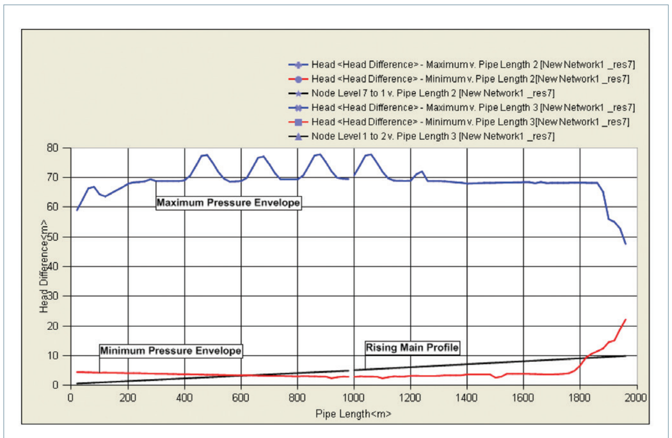
Graph 5 indicates a negative pressure situation in the rising main leading up to the wastewater treatment plant. This situation was created by upstream pumps in Pump Station W39 being too large and causing significant up and down surges when starting and stopping as evident from graph 6. Dividing the capacity over a larger number of smaller pumps would improve the situation.

Maximum dynamic system capacity

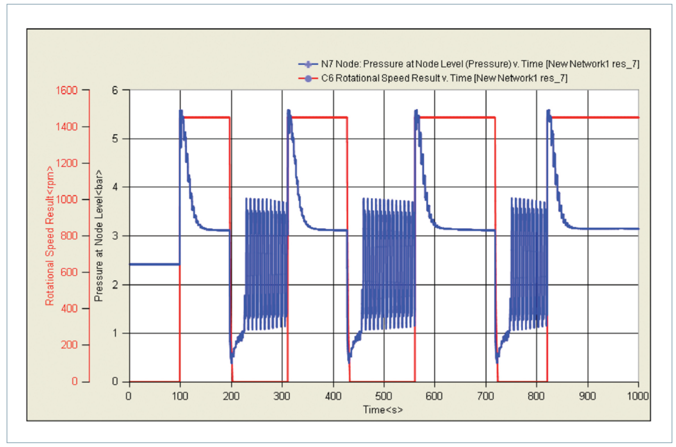
Total inflow from an UPWWF event is about 3.4m^3/s. Graph 4 shows the final Pump Station W39 delivering a total flow of up to 3.1 cubic meters per second (m^3/s) to the wastewater treatment plant. With the second pump still on standby, the overall dynamic system capacity would be about 4.5m^3/s and therefore well in excess of maximum inflow.



Graph 4. Discharge flow from selected pump stations, showing the offset in flow transport caused by pump pit storage filling and gravity mains flow delays.



Graph 5. Pressure envelope of rising main leading up to wastewater treatment plant, indicating significant negative pressure in its final rising main.



Graph 6. Significant pressure fluctuations at Pump Station W39 are caused by frequent pump 1 starts and stops.

Potential control system improvements

In this simulation, pumps were started and stopped by local water level switches. A control system looking upstream and forward feeding start and stop signals would result in a more even delivery to the wastewater treatment plant. In the event of breakdowns in downstream pump stations, it would also be possible to hold wastewater back in certain areas by using local storage volumes, thus avoiding overflow situations. Such control system optimization would be undertaken in further simulations.

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