SYSTEM-WIDE HYDRAULIC TRANSIENT ASSESSMENT FOR THE CITY OF OTTAWA

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ABSTRACT

Water supply and distribution systems are generally complex and dynamic, ever-changing in terms of size, the number and type of elements, the physical characteristics of the various elements as well as the demands, both in the short- and long-term, placed on the system. Furthermore, these systems are communicative in that pressure waves are able to travel through them and across jurisdictional boundaries. The management of such systems is therefore rather challenging and it is important for managers to understand system performance, including the response to hydraulic transients (i.e., waterhammer) which can and do occur for a variety of reasons and, when uncontrolled, often lead to premature aging of pipes and appurtenances resulting in increased leakage, increased potential for groundwater intrusion and general failures.

This paper summarizes the approach and findings of a targeted system-wide risk study conducted by the City of Ottawa, identifying relevant issues and complexities, structural and non-structural risk mitigation measures as well as recommendations for going forward. The importance of high-frequency transient pressure monitoring at strategic system locations coupled with appropriate data interpretation is illustrated.

INTRODUCTION

The City of Ottawa water supply and distribution system consists of 2 water treatment plants, 20 pump stations, and 14 reservoirs, and this system serves a population of approximately 750,000. While specific areas of the City are experiencing significant growth and development, the City (and the water system) as a whole can be classified as relatively steady, especially when compared to many other municipalities in Ontario.

The water system is well operated and maintained, and the City has previously undertaken many significant initiatives to improve the system performance, efficiency and reliability. However, due to the relative age of the infrastructure (more precisely the timing of original design and construction), the City's water system has traditionally been designed and operated without a strong or dedicated consideration of the risk of hydraulic transients. The key reasons behind this common industry omission have been the traditional 'black-box' understanding and approach to this topic, but also the belief that this type of interconnected (i.e., network and not transmission based) system significantly dissipates the transient pressure potential and therefore the risk.

A series of recent events, including a rash of watermain breaks and system reconfigurations, combined with a positive directive to increase understanding and to deal with hydraulic transients proactively, initiated this system-wide study. The overall goal of this study was three fold:

1. Increase awareness and demonstrate the importance of monitoring the hydraulic transient performance of existing and aging water systems.
2. Demonstrate the link between hydraulic transients and system operation, performance and risk.
3. To provide recommendations for minimizing the risk due to hydraulic transients and for improving system operation, from both a system wide planning and design approach and from a specific individual component assessment and investigation.

This paper presents a brief summary of the study, with a focus on some of the more tangible investigation and analysis results.

STUDY COMPONENTS

The components of this study were established following discussions of specific system concerns; including those arising directly from operation, historical developments, and future plans. The City provided a long list of suspected risks and concerns, and this risk was then used to develop a targeted scope consisting of many distinct components. A brief summary of these is provided below.

1. **Hydraulic Transient Training Seminar and Introduction** – A single day workshop to increase awareness of hydraulic transients and to demonstrate the routine aspects of operation that can increase the overall risk to the system.
2. **Montreal Pressure Zone** – Hydraulic transient analysis and hydraulic field investigation of the closed pressure zone, with a focus of addressing the risk of hydraulic transients in light of a high watermain break record.

3. **Glen Cairn Pump Station** – Hydraulic transient field investigation and risk assessment of the pump station discharge conditions for the purpose of improving operations and minimizing the risk due to hydraulic transients.
4. **Hydrant Flusher Program** – Review of the bulk water dispensing program with a consideration of hydraulic transients and with the focus on improving the protocols.
5. **Independent Review** – Peer review of a recent hydraulic transient analysis of a new system, with a focus on addressing the analysis shortcomings and improving the ultimate performance of the system.
6. **Meadowlands Pressure Zone** – Investigation and monitoring of transient pressures at Carlington Heights Pump Station for the purpose of assessing the impact of a recent change in the mode of operation.
7. **Transient Pressure Loggers** – Review of City's field pressure investigation equipment and protocols, with a focus on improving its capability to investigate hydraulic transient concerns and monitor system performance.
8. **Specifications for Transient Analysis and SCADA** – Review of City standards for the purpose of improving analysis and design diligence, and for increasing the system performance monitoring capability.

This paper provides a brief discussion of the analysis and findings for only two of the above mentioned study components. This paper provides selected and specific system examples, but the general principles can be applied to most water transmission and distribution systems.

GLEN CAIRN PUMP STATION

Glen Cairn Pump Station services Pressure Zone 3W, and comprises four (4) pumps on a single 1050 mm CPP discharge header. The operating pressure at the station is approximately 60 to 70 psi, and the peak flow rate during the winter months is approximately 750 L/s. The storage in the zone is provided by the Stittsville Elevated Tank, and the station comprises a single (albeit non-dedicated) SRV.

As part of this study, a high-frequency transient pressure monitor was installed at the discharge header of the station for a period of two (2) months in the winter in order to determine the nature of operation, and to identify any hydraulic and hydraulic transient risks and possible performance improvements. Figure 1 presents a sample 5-day pressure monitoring period, in which the **blue** recordings represent normal (i.e., steady) operating pressures, and the **red** recordings represent transient pressures (i.e., transient events).

As is visible in the sample pressure profile, the pump station operation is characterized by a series of routine pump changes, with 1 pump being the norm, and 0 and 2 pumps being the minimum and maximum. The transient pressure band for routine operation is typically between 40 and 80 psi. While this range is not of great concern, the frequency of pump changes (8 to 10 per day) was determined to be excessive. In most cases, the two pump mode of operation is limited to a duration of 20-40 minutes, after which the second pump is turned off. In other words, the storage in the zone was shown to not be used up to its optimum capability, thereby leading to a frequent pump operation that in the long-term tends to fatigue the system through the associated transient events. Figure

2 presents a unique series of non-routine pump changes that further demonstrate the cumulative risk of transients during current operations.

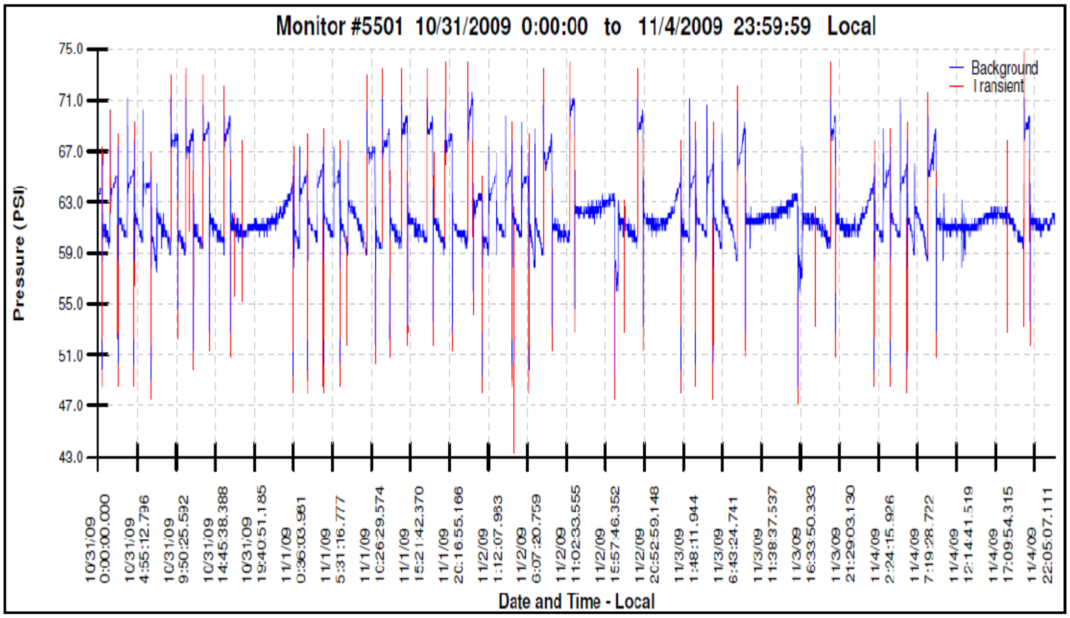

Figure 1: Sample 5-Day Discharge Pressure History at Glen Cairn PS

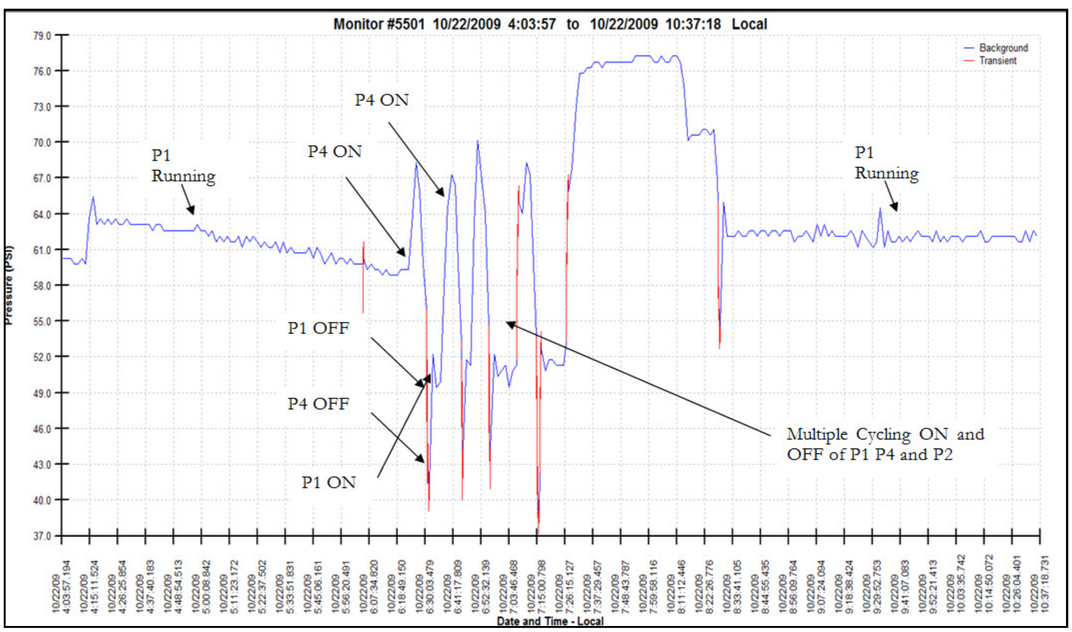

Figure 2: Pressure History for a Series of Pump Changes at Glen Cairn PS

While the two months of pressure monitoring yielded very few non-routine transient events, a power failure of a single pump was simulated as part of a series of planned field tests. Figure 3 presents the pressure profile for a single pump trip; a trip that resembles that of a typical power failure. The pump trip was shown to induce a negative transient pressure wave; a wave that would ultimately lead to several reflections within the system and a 40 psi drop the pressure at the station from 64 psi to approximately 24 psi. The system was shown to significantly fragment and dissipate the transient pressure wave energy, to the extent where no significant pressure wave reflections were observed.

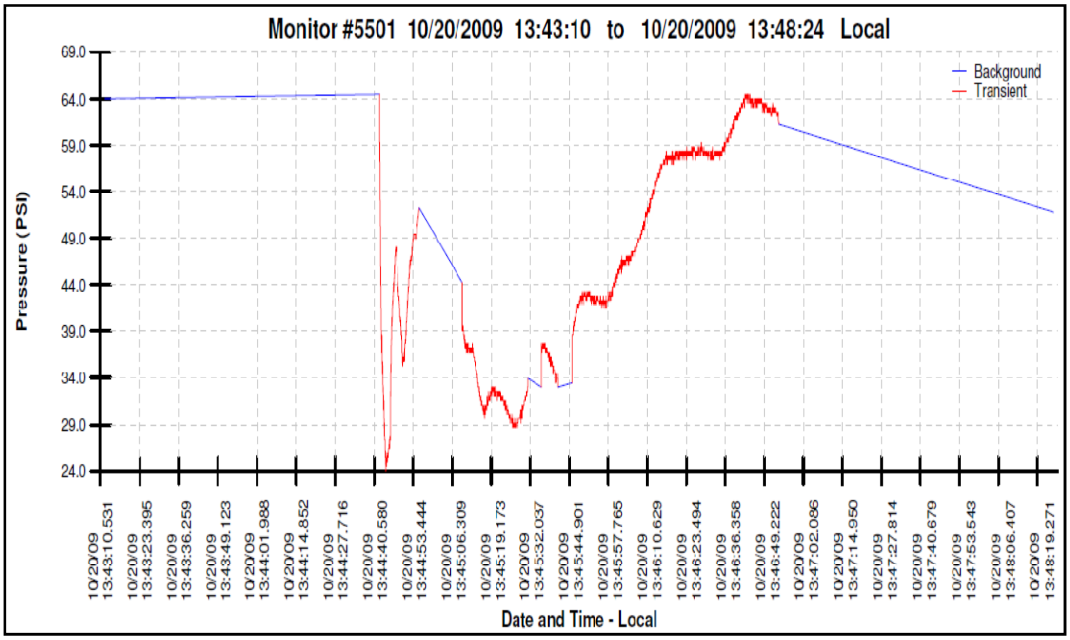

Figure 3: Pressure History for a Simulated Power Failure at Glen Cairn PS

The overall hydraulic transient risk (as identified via the field test and continuous transient pressure monitoring) was found to be quite mild. In other words, the pump station and distribution system components were not found to be at risk of immediate failure. However, the overall investigation did identify several additional concerns and recommendations for improvements; concerns which are briefly outlined below.

- All transient events induced by a change of flow at the pumps (e.g., pump start, power failure, etc), are greatest for a larger sized pump.
- Multiple pump operations and pump restarts following power failures are often performed without a proper intermediate standby period, thereby increasing the risks associated with transient pressure wave superimposition.
- The existing SRV is limited to pressure control when the Stittsville ET is out of service or out of communication. This valve serves its intended pressure relief purpose during this mode of operation, but has no benefit towards high pressure transients during normal operation.
- While not observed in the field, the risk to the system with the Stittsville ET out of service is likely quite different than the risk during regular operation. Without the back pressure from the tank, the 3W pressure zone would (and does) act much like a closed-pressure zone, in which the transient impact of rapid demand changes would become much more significant than that of a pump change or power failure. In this mode of operation, power failure events would act to depressurize the zone unless the backup generator is quickly brought online.
- The pump discharge valve closure and opening durations have been confirmed to be on the order of 1 minute, and the supporting transient pressure monitoring data confirms that this duration is sufficiently adequate.

- The transient pressure drops at the pump station arising from routine and non-routine events can translate into a more significant lower (and potentially below atmospheric) pressures in higher parts of the service area. Short lived low pressures such as this are merely a nuisance, but should the pressure in the service area drop below atmospheric, the nuisance can quickly become a public health risk.
- Routine pump changes during the operation of the diesel generators seem to induce more significant transient pressures. It does appear that the difference in the form of power contributes to a difference in the way the pumps and the motors operate. While the difference in transient event magnitudes is incrementally greater, the frequency of these events is a bit concerning. While possibly only a coincidence, most of the recorded non-routine transient events coincided with the period (or at least day) in which the diesel generators were operated.

In summary, this specific and non-intrusive, low-cost, investigation acted to identify the nature and magnitude of the transient risk in this part of the Ottawa water system. Furthermore, it subsequently identified necessary improvements to routine operational protocols, and at the same time reduced any associated liability through a proactive approach to dealing with hydraulic transients.

MONTREAL PRESSURE ZONE

The Montreal Pressure Zone in Ottawa is a small and closed pressure zone that has traditionally been fed from Pressure Zone 1E via the Montreal Road PS and Brittany Drive PS. (Brittany Drive PS has recently been taken offline.) The service area consists of residential and ICI users, including some large water users such as the National Research Council of Canada (NRC) and the Department of National Defence (DND).

The Montreal Road PS consists of four (4) pumps; two of which are equipped with Variable Frequency Drives (VFDs). The station is primarily operated in the VFD mode, in which case the pumps constantly adjust their speed to maintain a set discharge pressure. During the event that one of the two VFD pumps is not available, the station is operated in the constant speed mode; an operating mode in which two discharge-to-suction surge relief valves (SRVs), one at Montreal Road and one at Brittany Drive, are used to prevent high excessively high pressures in this closed pressure zone.

As part of the hydraulic transient risk assessment, numerical hydraulic modeling and field pressure monitoring techniques were combined in order to provide key insights on the behavior of this system. A high frequency pressure logger was installed at the discharge header of the Montreal Road PS and the transient pressure was monitored for a period of two months. The results of the non-intrusive pressure monitoring are shown in Figure 4; results which indicate a rare and unusually long period during which the station was operated in the non VFD mode.

In addition to the field investigation, hydraulic steady state and hydraulic transient models were exercised and developed for the zone in the TransAM software package for the purpose of identifying the transient conditions across the system. Using a combination of insight from the pressure monitoring data, SCADA records, and the hydraulic modeling, a number of transient event types were identified and studied, and their potential risks to the system were subsequently assessed. These include: VFD vs. constant speed pump operation, power failure, rapid demand changes, hydrant operations, and pump changes at the station. Additionally an investigative analysis was conducted on the pipe break patterns within the zone to determine possible correlation between high operating pressures and/or transient events.

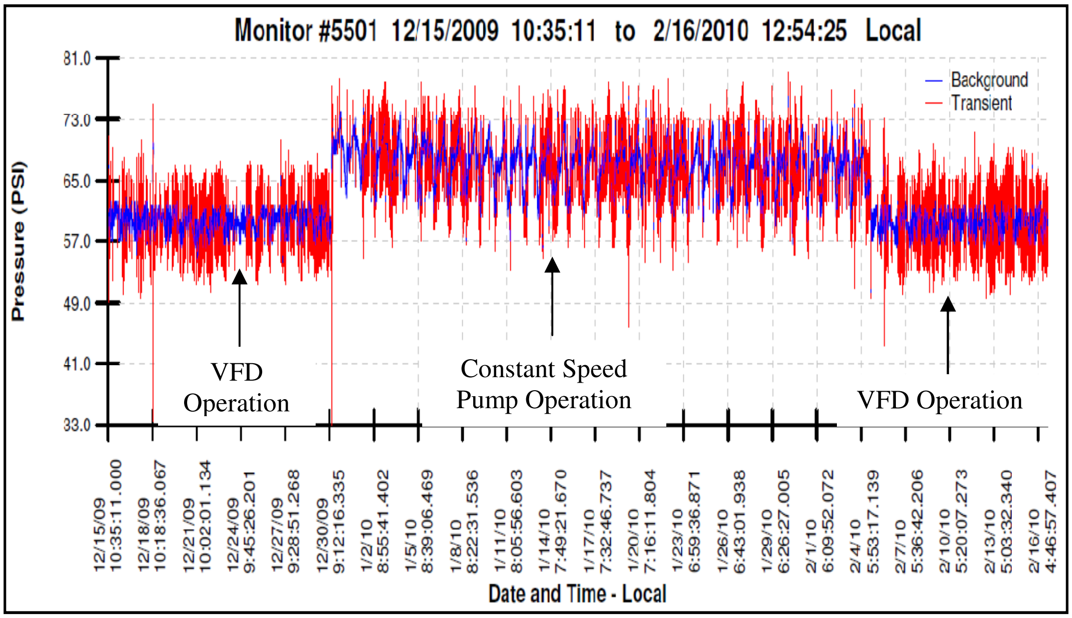

Figure 4: Pressure monitoring record from Montreal Road PS

VFD vs. Constant Speed Pump Operation: The analysis techniques confirmed that the operating pressures in the zone were approximately 10 psi greater for the constant speed pump operating mode during the winter month study period. While such a higher pressure can have a direct impact on the system (e.g., increased leakage, increased risk of watermain breaks, higher starting potential for transient events, etc.), one of the most intriguing byproducts was that the flow rate in this mode almost doubled. Due to the lack of storage and relatively steady winter demand, the cause of the increased flow rate could not initially be identified. Following a detailed SCADA record and field investigation, it was determined that at least part of the extra flow was caused by one or two of the pump station SRVs; valves which were essentially continuously relieving water back to a lower pressure zone during the constant speed mode of operation. While not necessarily a risk, this type of pressure control is inefficient from hydraulic, structural, and energy points of view.

Power Failure: A power failure was numerically simulated in order to demonstrate that without the presence of a high energy source such as storage, transient pressure wave reflections cannot be sustained. In other words, unlike in most storage based pressure zones, the hydraulic transient risk arising from a power failure is minimal. The risk to this type of system essentially comes in the form of pressure collapse – unless the back-up power is quickly used to restore the pressure. The pressure monitoring data and SCADA records identified one suspected power failure event, in which the pressures sharply dropped prior to the back-up generators coming online.

Rapid Demand Changes: Demand changes lead to changes in the flow rate which in turn lead to velocity changes and thus generate a transient pressure fluctuation. However, in a large system with storage and significant flow through pipes, most demand changes result in insignificant surge pressures. On the other hand, in the case of this small closed pressure zone, rapid demand changes (especially by large users such as the NRC or DND) can lead to significant transient pressure potential. A sample demand induced transient pressure range of 25+ psi is shown via a numerical model result in Figure 5. Such pressure fluctuations can be problematic in areas that already have high pressures (e.g., low elevation outlying areas), where transients induced from local demand changes can raise the overall pressure above the pipe's rating or lead to immediate short-term or fatigue based long-term failure. As is the case with most transient events, it is the rate of the change that must be controlled.

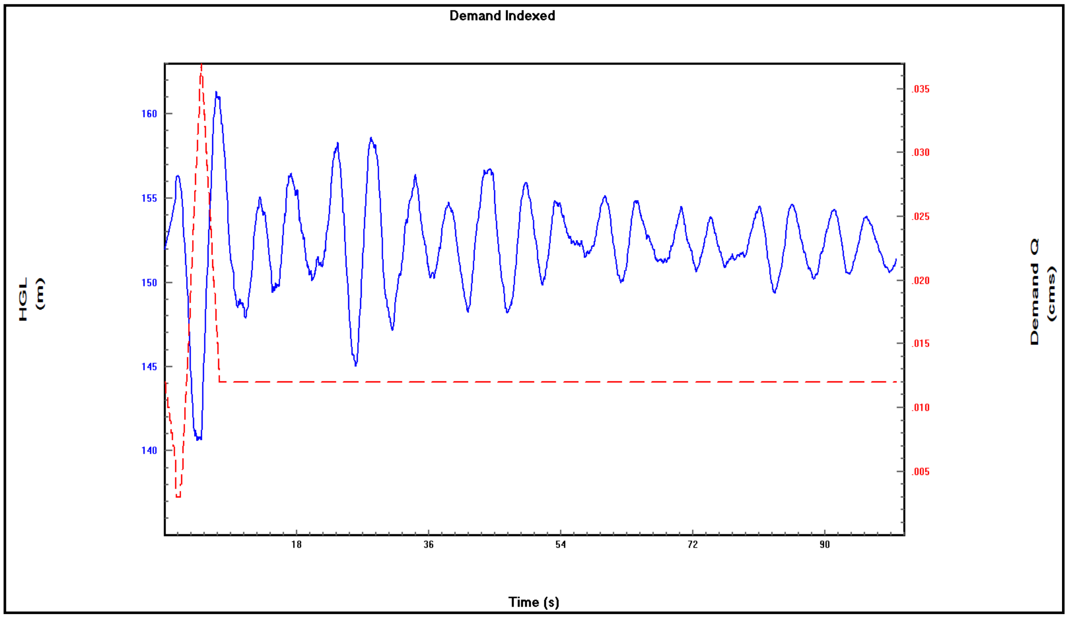

Figure 5: Pressure fluctuations induced by demand changes

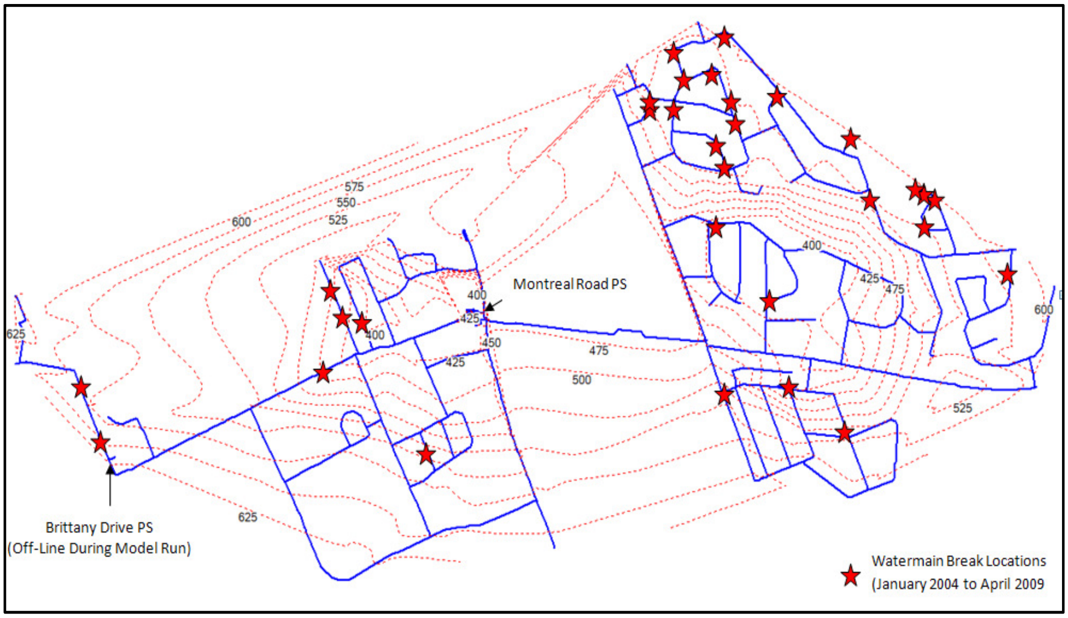

Figure 6: Watermain break locations in the Montreal Zone (January 2004 to April 2009) overlaid by VFD control pressure contours in the system under steady state conditions.

Watermain Break Analysis: A pattern analysis of watermain breaks was conducted by utilizing the data acquired from the numerical modeling and field monitoring, and by correlating these to 5 years of previous break records. As presented in Figure 6, a disproportionately high number of breaks have occurred in high pressure (low elevation) areas of the Montreal pressure zone. The normal and high operating pressures of 80 to 90 psi, combined with the pressure increase from the constant speed pump operation and the variety of transient events (and their excess pressure magnitudes) noted earlier, have likely significantly contributed to these breaks.

The above technical and case based examples have demonstrated some of the interesting connections between system operation, hydraulic performance, and hydraulic transient risk. In this specific case, the analysis identified several concerns and recommended a series of improvements and initiatives to improve the overall performance. The recommendations varied from improved pump control logic, revised surge protection, pressure management, proper hydrant operation, increased monitoring, and improved awareness and education.

CONCLUSIONS

The City of Ottawa water supply and distribution system is a relatively steady system; one that faces the same challenges as other systems do: aging infrastructure, increased complexity, tight regulation, and lack of resources. Even with these realities, the City continues to be proactive in its system operation and management. This paper presented a glimpse of the findings and results of a system wide hydraulic transient study that the City commissioned in order to identify a range of system threats and to improve the overall understanding and approach to hydraulic transients through increased awareness.

This paper demonstrated the benefits of system performance and risk monitoring via high frequency transient pressure monitors, and the combined benefit of using acquired data in conjunction with field investigations and numerical modelling. In a general sense, any system deficiencies, risks, and changes typically always show up through a transient pressure response. In other words, hydraulic transients present the pulse of the system, and are therefore good indications of stress. This paper provided examples of system risks in two sample cases involving the Glen Cairn Pump Station and the Montreal Closed Pressure Zone. The overall purpose and goal of the overall study (and this paper) has been to demonstrate how one proactive municipality has sought to improve its system operation through targeting and investigating parts of the water system that face a higher level of hydraulic risk.