

CITY OF VAUGHAN DISTRICT METERED AREA (DMA) PILOT PROJECT

Johnathan Nault, HydraTek & Associates*
Akter Hossain, City of Vaughan
Deepak Panjwani, City of Vaughan
Fabian Papa, HydraTek & Associates

***HydraTek & Associates, A Division of FP&P HydraTek Inc.**
216 Chrislea Road, Suite 204, Vaughan, Ontario L4L 8S5
j.nault@hydratek.com, 416-238-7681 Ext. 490

INTRODUCTION

The City of Vaughan is responsible for the distribution of water to (retail) customers within its boundaries, deriving water from the Region of York, being the wholesale provider of bulk water for local area municipalities in its jurisdiction. The Region of York, in turn, purchases the majority of its water, particularly that which is consumed in Vaughan from the Region of Peel and the City of Toronto, both of which produce their own water using Lake Ontario as its source. One of the results of this administrative structure is that the City of Vaughan has a relatively high marginal cost for the water it purchases when compared to municipalities that produce their own water. Accordingly, there is a strong financial incentive to ensure the efficiency of its distribution operation in respect of water loss management and control. Apart from that, there are over-arching benefits associated with both water and energy resource conservation, as well as operational and asset management matters which ultimately impact the level of service provided to its customers and the sustainability thereof.

As part of its ongoing evolution in this capacity, the City recently conducted a project which included the piloting of four district metered areas (DMAs) in various areas of the City, as well as the development of a strategy for implementing DMAs going forward. This paper briefly summarizes the project, conducted in 2018, and selected outcomes thereof.

PILOT DISTRICT METERED AREAS (DMAs)

Overview

This component of the project involved the design, construction and implementation of several DMAs in the City of Vaughan. This section discusses selected topics related to the project, including a sampling of results therefrom.

Selection of Pilot DMAs

The City identified the Pilot DMA areas based on a desktop assessment which considered: areas with older or metallic watermains; historical watermain break locations; areas with high historical water losses; areas which were easy to isolate with boundary valves; areas which required relatively few valve closures so as to mitigate potential water quality concerns; and areas that needed fewer flow meters. Further, it was intended that the learnings from the piloting of these selected DMAs would be used to help shape the subsequently developed city-wide DMA strategy.

Semi-Permanent DMAs

For this project, the City implemented what was termed as semi-permanent DMAs, being the implementation of permanent infrastructure, including flow meters in chambers, used for temporary DMA creation and short-term flow monitoring, being akin to temporary DMAs. In so doing, the City is positioned to (i) temporarily replicate the creation of the DMAs and conduct flow monitoring for purposes of trending against the baseline readings derived from this project, and (ii) to build upon these installations in the future for the creation of permanent DMAs.

Creating the DMAs

The creation of DMAs involve the isolation of sectors within a water distribution system such that inflow (and outflow, if applicable) points are limited and controlled. This typically involves the closure of several isolation valves along the boundary of the DMA and, while it should be clear and obvious that boundary integrity (i.e., tightness of valve closure) is critical, it is not necessarily easy to achieve in practice.

For instance, during the initial attempt to establish one of the DMAs in this project, it was discovered that there was an additional connection to the DMA that was not known of based on the City's historical drawings, models and GIS records. (This is an example of how conducting such activities yields benefits in institutional knowledge for ongoing operation and asset management of the system.) Apart from that one isolated occurrence, the integrity of each DMA boundary underwent a "zero-pressure test" whereby, in addition to the DMA boundary (isolation) valve being closed, an adjacent valve was also closed and a hydrant located between them opened to ensure that there was no flow. In most cases, the tightness was not proven upon initial closure, and several attempts to exercise each of the valves were needed to achieve the sought-after results. Accordingly, the effort and patience required to achieving the DMA boundary integrity is important to appreciate and plan for.

Size Matters

Critical to DMA implementation, like many other field monitoring and testing activities in water supply and distribution systems, is accurate and reliable flow measurement. More salient in respect of matters related to DMAs and water loss assessment is the accurate and reliable measurement of low flows, particularly those occurring overnight when demand is at its lowest. One of the key measurements in DMA water loss assessment is that of the minimum night flow (MNF) which is commonly defined as the minimum flow occurring over a rolling one hour duration (although current work by some of the authors relates to the investigation and application of a lower averaging period to improve estimation methods).

The ability for flow meters, particularly in-line flow meters such as those used in this project, to measure low flows is a function of the meter size. That is, the smaller the meter size, the higher the flow velocities through the meter and the more capable the meter is of firstly detecting the flow and, secondly, measuring it accurately and reliably. Further, a reasonably accurate estimation of MNF is needed and, ideally, the detection limit of the meter would be sufficiently below that level so as to improve the likelihood of quality measurements. In the case of multiple inlets to a DMA, not only is a good MNF estimate needed, but also an understanding of the likely distribution of inflow from each of the inlets, and for which a reliable hydraulic model is of value.

While seemingly simple in concept, the practice of flow measurement within distribution systems is not at all commonplace, particularly for the purposes discussed herein. What complicates matters is that the sizing of pipes in distribution systems is generally governed by the flows that need to be delivered for fire-fighting requirements and which are often two orders of magnitude higher than what the MNF might be for a particular DMA. Accordingly, the flow rates and velocities in the distribution piping, particularly during overnight periods, can be extremely low and, as such, requires smaller meter sizes to properly detect and measure.

For this project, wherever pipe sizes were too large such that corresponding meter sizes would be at risk of not or poorly measuring the flows, reducers were installed such that appropriate meter sizes could be used. While all DMAs considered two inlets, three of them had meters at both inlets, while one DMA used a meter at one of its inlets with a pressure reducing valve (PRV) at the other. The rationale behind this latter case was to ensure that the meter sizes used weren't too small – the single inlet allowed for a larger meter size – and the PRV allowed for the provision of additional supply in the event of an emergency condition resulting in a high demand (e.g., fire). In order to support the decision to locally reduce pipe diameters to accommodate appropriate meter sizes, hydraulic modelling and before-and-after field testing was conducted. In general, the hydraulic performance of the DMA under high demand conditions was not significantly impacted by the implementation of the DMA itself (and the associated closure of several boundary valves) and the locally reduced pipe sizes.

Sample results from the flow monitoring exercise are presented in Figure 1 and which indicates that the lowest flows recorded were above the meter's lower detection limits. This was indeed the case for all DMAs and, as such, the data collected was accurate and reliable.

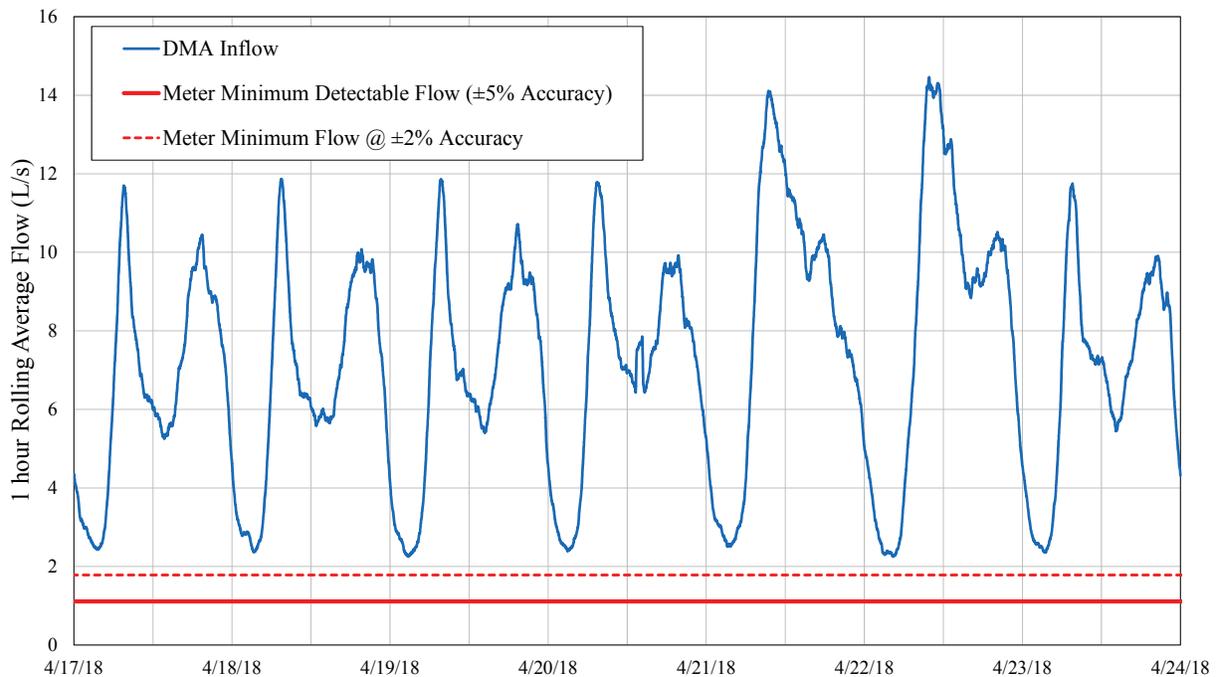


FIGURE 1. SAMPLE FLOW DATA RELATIVE TO METER DETECTION LIMITS

Considering the Impacts of Irrigation

As noted above, the DMAs implemented in this project are identified as semi-permanent, involving permanent infrastructure with DMAs being established, and measurements taken, on a short-term basis. Accordingly, this project included the short-term measurement of flows into each of the DMAs (i.e., on the order of one-to-two weeks in duration), importantly noting that the measurements were taken during colder months so as to avoid the impact of irrigation or other outdoor watering uses. In fact, the use of automated irrigation systems during summer months can result in demands that completely dwarf the typical diurnal demand pattern, depending on the size of the DMA, its land uses and the affluence of the customers within it. One of the key recommendations resulting from this project was to ensure that future flow monitoring be conducted during non-irrigation months when attempting to trend MNF measurements.

Consumption Patterns

One of the striking results, although not necessarily surprising, was the consistency in consumption patterns for the three predominantly residential DMAs implemented for this pilot project. To illustrate this, Figure 2 presents the ratio of hourly average flow to daily average flow during weekdays for each of the residential DMAs individually, as well as the average of these ratio amongst these DMAs. The similarity in demand pattern is evident, and the results also suggest that all of these DMAs are performing similarly with respect to leakage characteristics; that is, there is no clear evidence of any one of these DMAs performing poorly relative to the others, and the ratios of minimum night flow to average daily flow, are not suggestive of significant leakage.

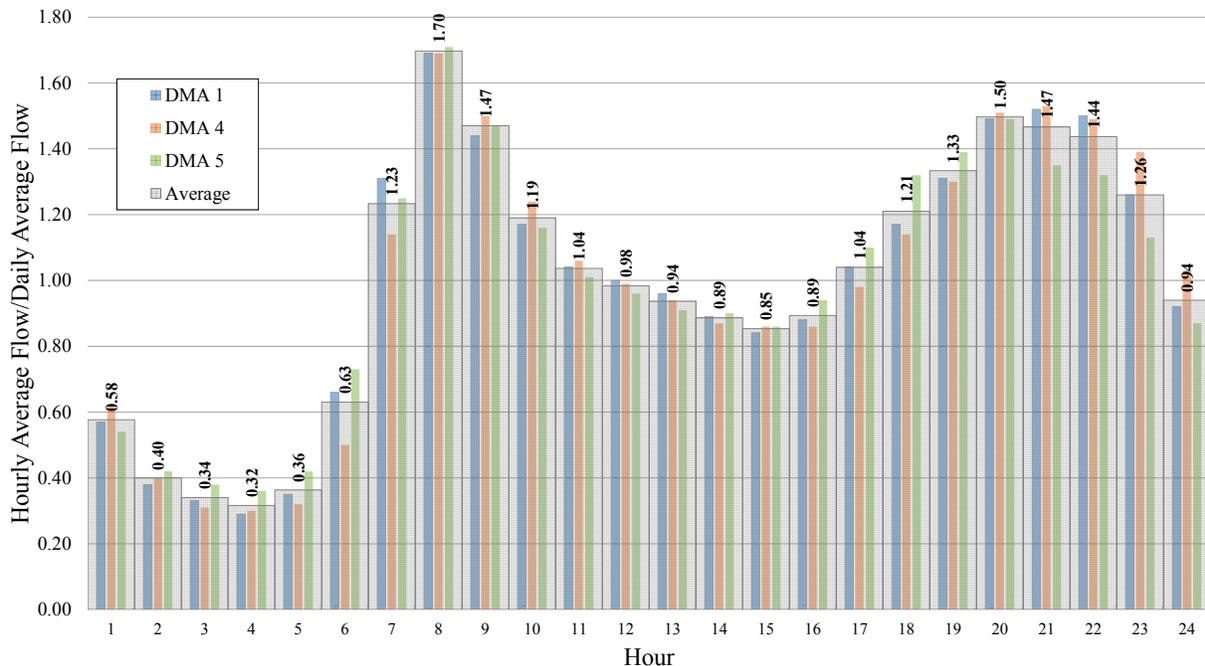


FIGURE 2. AVERAGE WEEKDAY CONSUMPTION IN RESIDENTIAL DMAS

With the data made available from this project, a variety of analyses can be undertaken which reveal information relating to customer behaviour and system performance which may be helpful. For instance, the results presented in Figure 3 show the profiles for individual days of a week for one of the residential DMAs. Observations that can be easily made include (i) the strong similarity of (most of) the weekdays (in **blue**), discussed above as well, (ii) the similarity of the weekend days to each other (in **orange**), as well as the differences between Saturday and Sunday consumption patterns, and (iii) the dissimilarity of the Monday data (in **black**) from its weekday counterparts, being the result of a change in customer behaviour following an ice storm the night prior, resulting in difficult morning road condition, the closure of numerous schools and cancellation of bus services to them. While perhaps not of direct relevance to the project itself, the results are interesting (to at least some of the authors) and provide an indication of what can be done with data (if it is collected in the first instance, and analyzed in the second).

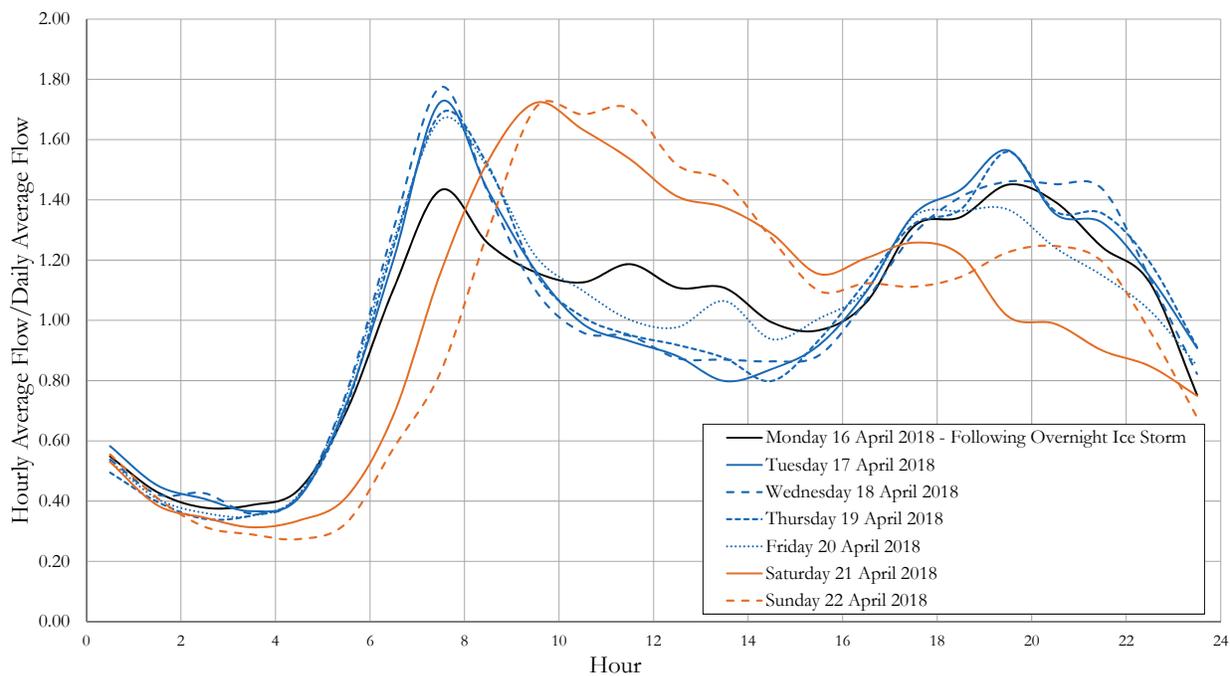


FIGURE 3. DIURNAL FLOW PATTERN INTO RESIDENTIAL DMA OVER 7 DAYS

Only one non-residential DMA was considered in this project, and the results of the flow monitoring exercise produced the results presented in Figure 4 show, as is reasonable to expect, an increase in water consumption during typical working hours. Although not shown herein, the weekend flow profiles were generally uniform throughout these days.

It should be noted that the data presented herein was collected in (colder) periods during which landscape irrigation is not practiced, being an important consideration when assessing diurnal demand patterns and MNF characteristics.

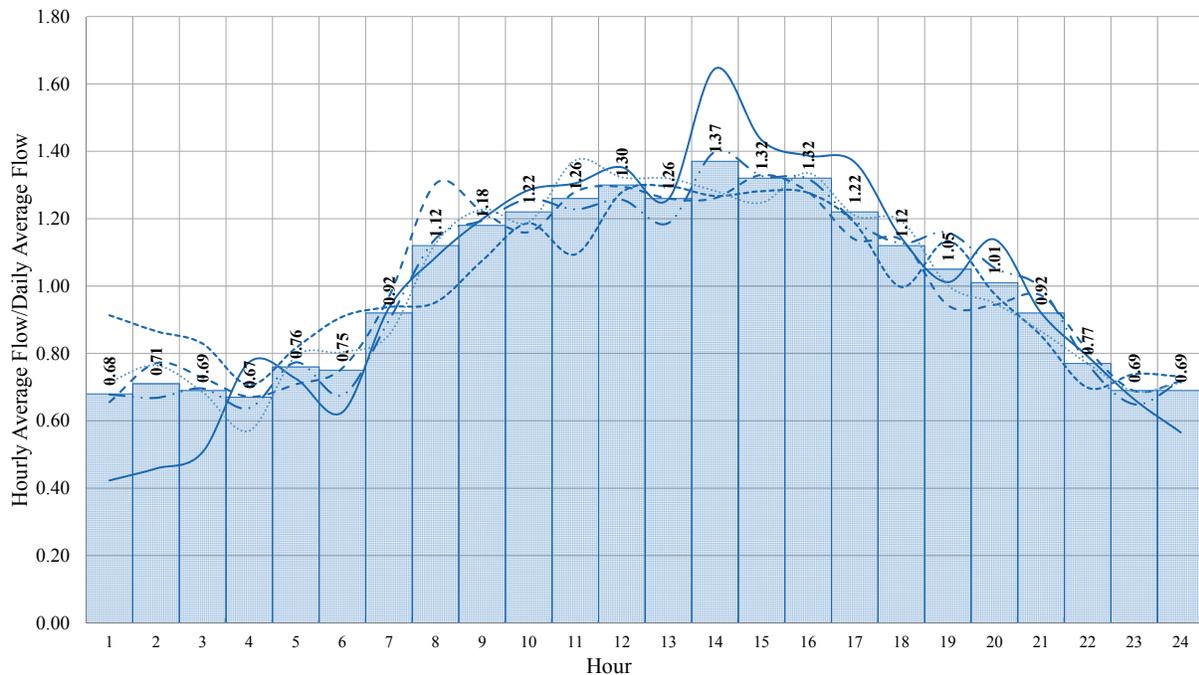


FIGURE 4. AVERAGE WEEKDAY CONSUMPTION IN NON-RESIDENTIAL DMAS

General Discussion of Results

Although the project has been concluded, the results and recommendations from this work are still under consideration and a generalized discussion of results are presented here.

For the residential DMAs, the ratios of MNF to average monitored flow (during the 1-2 week monitoring period for this project) and average billed consumption were within the range of what is typically considered a reasonably well-performing system. This finding was consistent with the MNF rate normalized against the number of connections in the DMAs. This is not to say that there is no leakage, or not a meaningful amount of leakage, but rather that there are no obvious signs of meaningful leakage. With the City planning to move forward in the coming years with advanced metering infrastructure (AMI), from which the customer consumption data from individual meters can be obtained for the same time frame as the flow monitoring into the DMA, the City will be in a position to conduct a mass (water) balance to more accurately identify the difference between these quantities. The ability to conduct such a mass (water) balance was not practically possible for this project given the number of connections in the DMAs if individual meter readings were to be taken at the beginning and end of the monitoring period, and that the monitoring periods were for a significantly shorter duration than the typical 2-month billing cycle.

Similarly, for the non-residential DMA, it was not practically possible to conduct a mass (water) balance to compare inflows to the DMA against consumption, although the infrastructure is in place for future such analyses once the AMI system is established. The topology of the DMA, however, did lend itself well to its division into two sub-DMAs of roughly equal size, and for which monitoring data was collected to compare against the results against the condition when the entire DMA was operational. While the results did suggest some differences in flow characteristics, more work is needed to understand the source of these differences. Given the

industrial and commercial business uses in the area, there can be a considerable impact of even a single user on the monitoring results.

In general, although the results obtained from the monitoring exercise may not indicate that there is a widespread leakage issue in the DMAs tested, it is important to note that there remains a substantive difference between the overall volume of water supplied to the City relative to consumption from the City's top-down water audits conducted in accordance with IWA/AWWA methodology. Accordingly, there remains work to be done to arrive at a convergence between the results of such top-down approaches and bottom-up approaches, such as those conducted as part of this project. This project accordingly represents a first step toward the potential development of a broader and more meaningful system of DMAs and related analytics. The development of a City-wide strategy, discussed below, considers these findings and is based on an approach of progressive investment targeted to areas in a prioritized manner based on the likelihood of identifying opportunities for improvement, thus emphasizing returns on investment made.

GOING FORWARD STRATEGY

In order to develop a strategy for going forward that would position Vaughan for the future, taking advantage of ongoing advancements in smart infrastructure systems so as to effectively manage its assets and deliver services efficiently, several factors were considered. Firstly, it is important to recognize the time required for the evolution to a highly sophisticated system of water loss management which depends on matters such as funding availability over time, capacity building both within the organization and amongst service providers, and other initiatives which are supportive and complementary. On this latter topic, and as noted above, the City has approved a plan to implement an AMI system over the coming years, and integration of the data from DMAs with AMI will be able to power analytics to understand system behaviour as well as detect concerning events and trends at an actionable level and in a timely manner.

Of course, the value of any investment is a function of its returns. In the case of water loss reduction, the returns include (i) the direct financial returns associated with reducing the amount of water the City purchases (imports), and (ii) the indirect returns which are elucidated as follows:

- **Improved system knowledge** results from the activities involved in conducting the field work required to establish DMAs and other water loss management activities and which may include matters such as the identification of inoperable or broken valves or hydrants, the existence (or non-existence) of pipes that are not accurately recorded in information systems, understanding of system behaviour and consumption patterns, etc. This improved knowledge and resultant understanding can then be used to inform better decisions in relation to system operations and asset management.
- **Synergies** with other initiatives (e.g., AMI) can further inform decisions at a deeper level through the integration of independent, but interrelated data sources, leading to better operations and asset management and overall system optimization.
- **Reduction in energy consumption** which, although is not relevant to Vaughan specifically as it is generally not responsible for pumping (except in some isolated areas). In fact, these benefits accrue to upstream players including the City of Toronto as well as the Regions of Peel and York. Accordingly, the reduction in energy consumption

associated with water loss reduction is felt at a larger scale and provides a broader-reaching benefit.

- **Water resource conservation** which, similar to above, provides a broader-reaching benefit in that less resource extraction and lower volumes of water for treatment result.

Approach

With the above matters in mind, a “two-dimensional” approach was advanced for this project consisting primarily of (i) the prioritization of future DMAs based on the likelihood of leakage so as to focus initially on the opportunities for highest potential value creation (i.e., the “lowest hanging fruit” in terms of potential water loss reduction), and (ii) the intelligent implementation of DMA types, in terms of sophistication (and, hence, cost), so as to promote the cost-effective implementation of same. Prior to applying the above approach, however, the City’s water distribution system was divided into 54 DMAs based on system topology and other characteristics. In the case of Vaughan which has a number of transmission mains owned and operated by the Region of York throughout its jurisdiction, many of the DMA boundaries necessarily occurred at connection points to this infrastructure.

The prioritization of DMAs was based on several factors, including: (i) the total length of metallic watermain in the DMA, noting that approximately 90% of pipe breaks in Vaughan occur on metallic pipes; (ii) the length-weighted average age of watermains in the DMA which assumes that older pipes present a higher likelihood of leakage; (iii) the number of connections in the DMA, recognizing that broader industry evidence has identified that leaks at service connections often represent a high fraction of overall leakage; (iv) watermain break history in the DMA which assumes that, the higher the break frequency, the higher the vulnerability of the pipes therein for whatever reason (e.g., construction issues, soil corrosivity, etc.); and (v) pressure characteristics in the DMA which itself was broken down into two components, including average pressure which relates the operating level for the pressure district in question to the average elevation in the DMA, as well as pressure dynamics which is intended to consider the fluctuations in sustained pressures in the DMA as well as hydraulic transient characteristics. On this latter topic of pressure dynamics, there was limited information available as at the time this work was conducted, although one of the recommendations resulting from the project was to develop a proper understanding of this through long-term pressure monitoring exercises, some of which were underway in a parallel project at the time. To each of the above factors, a scoring methodology was applied, with scores ranging from 0 to 10, with higher values representing higher likelihoods of leakage. Certain factors were scored based on a linear scale (i.e., length of metallic pipe, break history, number of service connection), while others were scored based on a non-linear scale (i.e., watermain age, average pressure) based on historical records that were available from comparable municipalities in Ontario which related these matters to other characteristics. For instance, the data set used indicated a strong non-linear relationship between the frequency of watermain breaks and both watermain age as well as average pressure; these relationships were used herein to score the factors noted above for each DMA. For the case of pressure dynamics, a quasi-quantitative approach was taken based on the limited data available to assess this factor, as noted above.

Each of the above factors was assigned a weighting which was collaboratively agreed upon through dialogue between the City and project team, and overall scores were determined. Given

the lack of data available for scoring the pressure dynamics factor, it was given a relatively low weighting and, as noted below, this can be revisited over time.

In relation to the prioritization methodology noted above, it is noted that the details of the approach can be refined over time as more information becomes available. For instance, considering the total length of watermain, irrespective of material, or in conjunction with the currently considered metallic pipe length, is reasonable. As well, adjusting the weightings of each factor to better represent their individual importance, based on evidence derived from field activities, is reasonable to consider. In fact, the revisiting of this strategy periodically (e.g., every 5 years) for this very purpose was one of the project’s recommendations.

Results

The resulting scoring for each of the DMAs is presented in Figure 5 which breaks down the overall score for each DMA into its component parts and ranks the DMAs by score, from highest to lowest score (i.e., highest to lowest likelihood of leakage). What is evident from the figure is that two DMAs stand out as having rather high scores, both including and excluding the influence of watermain breaks within them. Accordingly, these DMAs were recommended to be among the first for the City to expend some effort in investigating. As noted above, these results are naturally dependent upon the scoring methodology applied, including relative weightings for each factor, although it is worthy to note that a sensitivity analysis on the weightings did not yield material differences in the results. Whatever the case, the results of this analysis are now helpful for the City to prioritize where it should direct its energies.

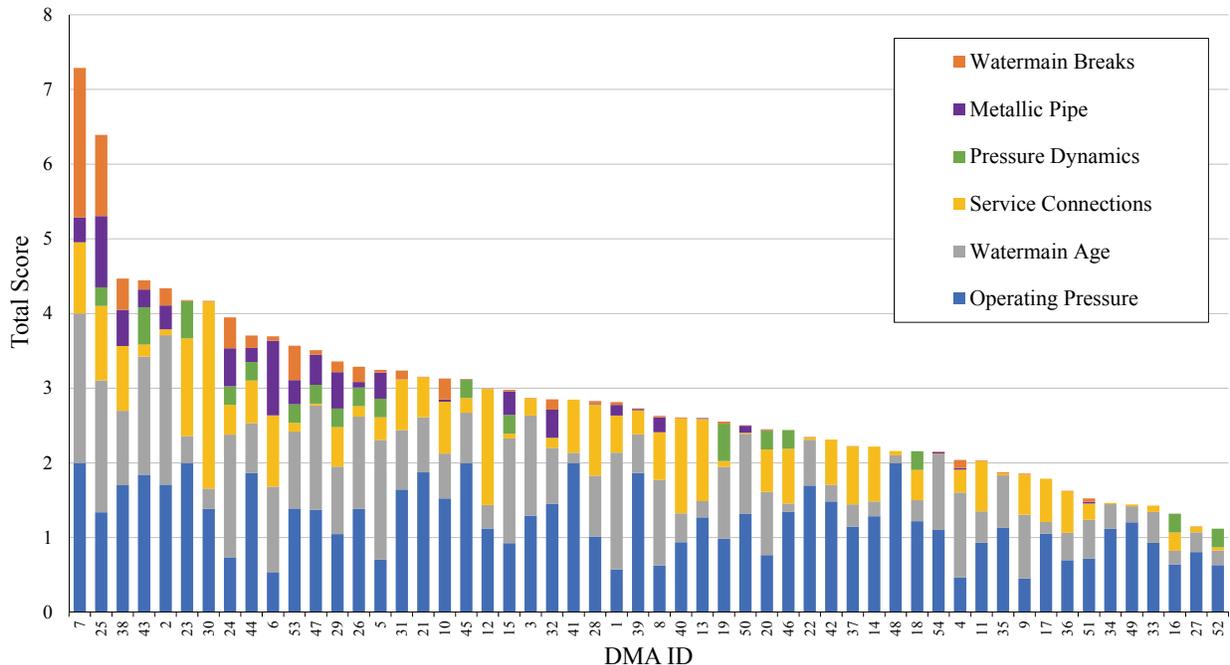


FIGURE 5. DMA PRIORITIZATION SCORING RESULTS

Progressive Implementation of DMAs

The implementation of permanent infrastructure for establishing DMAs can be a costly and disruptive undertaking, and it is important to maximize the potential for realizing a system improvement (i.e., return on investment, including both direct financial returns as well as indirect returns) in order to demonstrate the success of the approach and improve confidence therein so as to promote ongoing investment. In this regard, even information which helps to improve future decisions can be viewed as a return on the investment, although the value of this still needs to meet the test of reasonability in order to justify investments of this sort.

For this project, a framework for the progressive implementation of DMAs, in terms of their sophistication, was developed so as to support investment decisions that are cost-effective and promote improving overall returns. In general, the framework firstly considers the prioritization of the DMA, or whether the DMA is strategic or opportunistic for implementation, such as whether there is other construction activity planned as in the case for new development, road reconstructions, or other system upgrades. These latter cases can sometimes leverage external funding sources, and often present opportunities where overall costs can be reduced relative to separate implementations. It is obviously much more costly to implement permanent infrastructure in an established (built-up) environment rather than a greenfield situation or where construction is occurring for other reasons.

The framework, illustrated in Figure 6, also considers the use of temporary DMAs or, more specifically, temporary measurements of flow (and pressure) characteristics in DMAs, the data from which will help to identify the potential and nature of leakage in the DMA and, from there, planning for future water loss reduction activities can occur. When warranted, deeper levels of investment in permanent infrastructure in relation to implementing permanent DMAs or possibly pressure management areas (PMAs) can be supported on the basis of field-derived evidence.

As noted above, the effectiveness of temporary DMAs is highly dependent upon the available flow metering technology and whether or not the equipment considered is capable of accurately and reliably measuring low flows, particularly during overnight periods where demand is at its lowest. Accordingly, DMA-specific consideration is necessary to achieve success in field measurements.

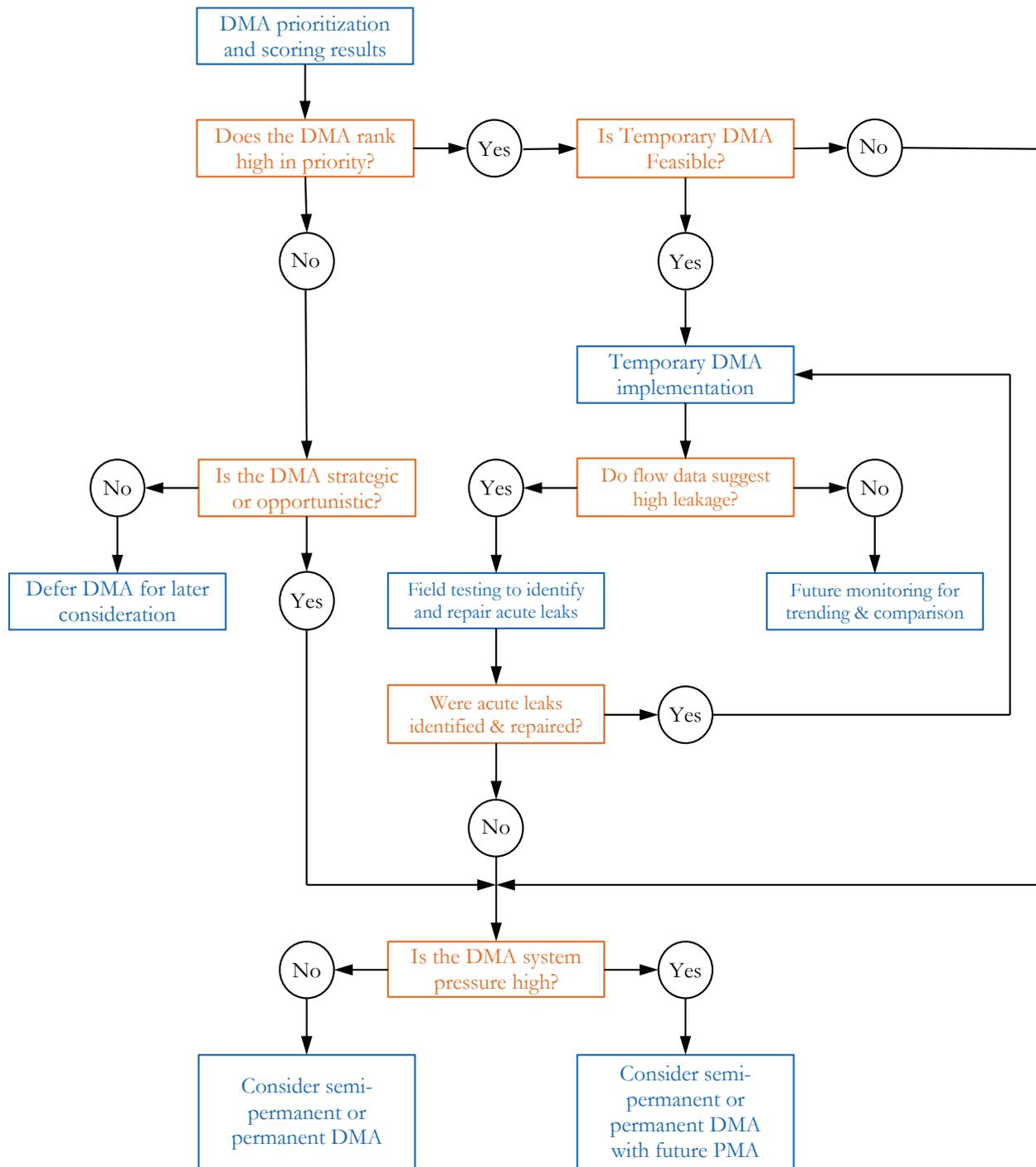


FIGURE 6. CONCEPTUAL DECISION-MAKING FRAMEWORK FOR DMA IMPLEMENTATION

CONCLUSIONS

Through this project, the City of Vaughan has taken the initial steps towards developing and building the internal capacity to work towards the evolution of a City-wide system that will be capable of furnishing the relevant information to power decision-supporting analytics for the optimal operational and asset management of its water distribution system. In recognition of the time and investment required to establish these systems, both physically in the field as well as institutionally, and in light of the uncertainties associated with these practices, the strategy developed for DMA implementation across the City is one which intelligently and progressively deploys resources, financial or otherwise, in a targeted and cost-effective manner so as to judiciously allocate such resources (i.e., investments).

ACKNOWLEDGEMENTS

This project was made possible by the support of the Clean Water and Wastewater Fund (CWWF) with contributions from both the federal government (Infrastructure Canada) and the provincial government (Infrastructure Ontario). As part of the project, interactions were held with other municipalities so as to share results, experiences and insights, including Halifax Water as well as the Cities of Ottawa, Guelph and Hamilton and whose participation in this process is gratefully acknowledged. Quite importantly, the contribution of the City's then project manager, Tara Clayton, currently with the Region of Niagara, to the success of this project is particularly worthy of note. Finally, operations staff at the City of Vaughan deserve thanks for their devotion to this project amongst numerous other competing demands at the time it was conducted; their efforts throughout the project, and particularly during the numerous overnight construction activities, including on weekends and always during cold winter weather, to help make this project a success is much appreciated and has not gone unnoticed.

NOTATION & ABBREVIATIONS

| | |
|------|----------------------------------|
| AMI | Advanced Metering Infrastructure |
| AWWA | American Water Works Association |
| CWWF | Clean Water and Wastewater Fund |
| DMA | District Metered Area |
| IWA | International Water Association |
| MNF | Minimum Night Flow |
| PMA | Pressure Management Area |
| PRV | Pressure Reducing Valve |