# RECONCILING DESIGN STANDARDS ACROSS JURISDICTIONAL BOUNDARIES: EXAMPLES FROM YORK REGION

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## INTRODUCTION

This paper discusses the process followed for the estimation of a suitable design flow to be applied in the design and analysis of a sanitary sewer drop structure upgrade to accommodate development growth in the contributing sewershed beyond that envisioned in its original design. While seemingly straightforward in concept, this matter gave rise to issues over the design criteria to be applied given its location: at the interface between two jurisdictions, namely York Region ("York") and the City of Markham ("Markham").

By way of context, the organization and management of wastewater (sanitary sewage) services in York is shared among the upper-tier municipality (York) and its nine lower-tier local municipalities, including Markham. York is generally responsible for trunk collection and conveyance as well as treatment across the region as a whole, and Markham is responsible for local collection and conveyance within its municipal boundary. As a result of these different responsibilities, there is also a difference in perspectives and resultant risk profiles which are manifested in their respective design criteria. Moreover, the differences in design criteria often become quite apparent at the interfaces between these systems.

Being responsible for smaller-scale systems (or, rather, components of broader systems), York's local municipalities (such as Markham) naturally gravitate to design standards that account for the generally wider range of uncertainty and variations in sewage generation associated with such systems. In contrast, being responsible for infrastructure systems (or components thereof) servicing larger-scale areas where variation in sewage generation is generally attenuated, York applies design standards suitable therefor. Accordingly, the design standards for local municipalities generally produce larger hydraulic loading conditions than those applied by York. Nevertheless, both of the approaches are valid based on their individual perspectives, and it is recognized that the provision of overall wastewater collection services to any customer in York is, in reality, from an integrated system.

This paper discusses the assessment of design flow at one of these jurisdictional boundaries, particularly for the upgrading of a drop structure to transition from the local municipality's shallow collection system to one of York's deep trunk sewers. As a result of the differences in design criteria, initial estimates in design flow varied by a factor of approximately two, a considerable margin and for which a deeper analysis was warranted in order to support the time-sensitive construction upgrade to meet the growth demands within the relevant sewersheds. This assessment considered the following: (i) historic long-term flow monitoring data from the sewersheds tributary to the drop structure in question; (ii) the design storm pattern and historic rainfall data selection for rainfall-derived inflow and infiltration (I/I); (iii) the statistical analysis of water consumption data; and (iv) the peaking factor for domestic sewage generation. Moreover, uncertainties in the key input parameters were assessed, using: (i) the root sum of squares method to home in on an appropriate per capita sewage generation rate (it is demonstrated below that the underlying data generally follows a Gaussian distribution which supports the use of this method); and (ii) the application of Monte Carlo analysis to assess the impact of uncertainties in each of the input parameters on the uncertainty characteristics of the resultant design flow estimate (noting that this method implicitly assumes the independence of the individual input variables which is reasonable for this application). The ultimate design flow selection was informed by these analyses and more explicitly balanced risk with infrastructure sizing (and cost).

The overall outcome of the above process was the establishment of a design flow that matched neither of the criteria applied by each of the jurisdictions precisely, but rather employed a set of criteria that was customized to suit the application at hand. The depth of analysis undertaken, based on field measurements and other reliable data sources, produced a technically sound and defensible result which was mutually agreeable. Further, this experience highlighted the value of re-assessing design criteria where there is the potential risk of over-investment due to the application of overly conservative criteria (or, conversely, the risk of under-investment due to the application of insufficiently conservative criteria). That is, where warranted, the application of such approaches will promote the "right-sizing" of infrastructure investments, and may be important in justifying the deferral of major capacity upgrades by understanding and exploiting the capacity of existing systems (i.e., "infra-stretching"). This is becoming increasingly important as municipalities in Ontario face the combined impact of: (i) existing infrastructure systems approaching the end of their useful lives; (ii) the strong trend toward intensification (densification) of existing urban areas and the resultant stresses imposed on the supporting infrastructure; and (iii) the cost implications associated with construction of new (and/or upgrading of old) infrastructure in built-up urban areas.

These concepts may be equally applied to water supply and distribution systems, and it is a valuable dialogue to engage in, particularly for York given the numerous interfaces between the Region and its local municipalities – and which are collectively responsible for delivering an acceptable service to the same set of customers – in light of the development pressures it faces (as mandated by the Province of Ontario). The intention of this paper is to discuss the process followed for the above noted sanitary sewer drop structure in Markham as an example in order to help facilitate a dialogue and the informed migration towards the rational selection of design parameters for key infrastructure system elements within York. It is reasonable to expect that comparable situations are expected to arise going forward for the reasons noted above and, for the sake of both economic efficiency as well as decision-making efficiency, developing approaches for the establishment of rational and defensible alternative design criteria for application in particular circumstances will improve comfort levels as well as streamline design and approval processes.

## VARIABILITY REDUCES WITH INCREASING POPULATION

It is generally well known and understood that the variability of hydraulic loading diminishes with the system and population size of the service area in question. This statistical phenomenon is the basis of the Law of Large Numbers which, in the context of sanitary sewage, would state that as the number of people in a sewershed grows, the average sewage generation rate will approach the average of the entire population. This similarly applies to water demand where there is data available at the individual customer level, albeit commonly based on monthly or bi-monthly meter reading frequencies which are not particularly useful for a granular statistical analysis of daily consumption data. That said, there are some jurisdictions in Ontario where hourly data is available where Advanced Metering Infrastructure (AMI) systems are installed.

A sample statistical analysis of daily water consumption records from an Ontario municipality with an AMI system is provided in Figure 1 (noting that the values on the y-axis are not provided for reasons of confidentiality and anonymity). Nonetheless, the graphic amply demonstrates the concept that the variability, as measured in this case using the 95% confidence interval (i.e., spanning from the $2.5^{th}$ to the $97.5^{th}$ percentile of values in the data set), rapidly decreases as the sample size (in this case households) increases initially from nil, and continues to decrease thereafter. The graphic also demonstrates that the data reasonably follows a traditional Gaussian (or "normal") statistical distribution which is useful when considering probabilistic approaches to the application of this data. These results were developed using what is often referred to as a "bootstrapping" analysis whereby the data set is randomly sampled for each quantity on the x-axis numerous independent times to derive the statistics relevant to each vertical "slice" along the axis in order to provide, in this case, the average as well as lower and upper bounds of the 95% confidence interval.

The reduction of uncertainty with increasing customer and population size is also recognized in common design guidelines. In particular, both the Harmon and Babbit formulas (MECP, 2008a) for sanitary sewage quantity peaking factors follow a similar trend as that indicated in Figure 1. As well, in relation to water supply and distribution, recommended peaking factors similarly reduce with increasing population size (MECP, 2008b). Importantly, these guidelines clearly state that the use of actual site-specific data is encouraged and that the use of monitoring records and characterization studies is encouraged. This is precisely the approach that was taken to arrive at a rational and defensible design flow estimate for the sanitary sewer drop structure replacement.

Accordingly, as it relates to this specific topic of this particular paper, it is not surprising that the design criteria applied by Markham produce higher flows than the design criteria applied by York. Their relative perspectives are different by virtue of the scale of infrastructure they respectively deal with. As noted earlier, in the case of the drop structure in question, the resulting initial design flow estimates differed by a factor of approximately two, demonstrating the potential for challenges and tensions that need to be resolved to advance infrastructure planning, design and implementation.

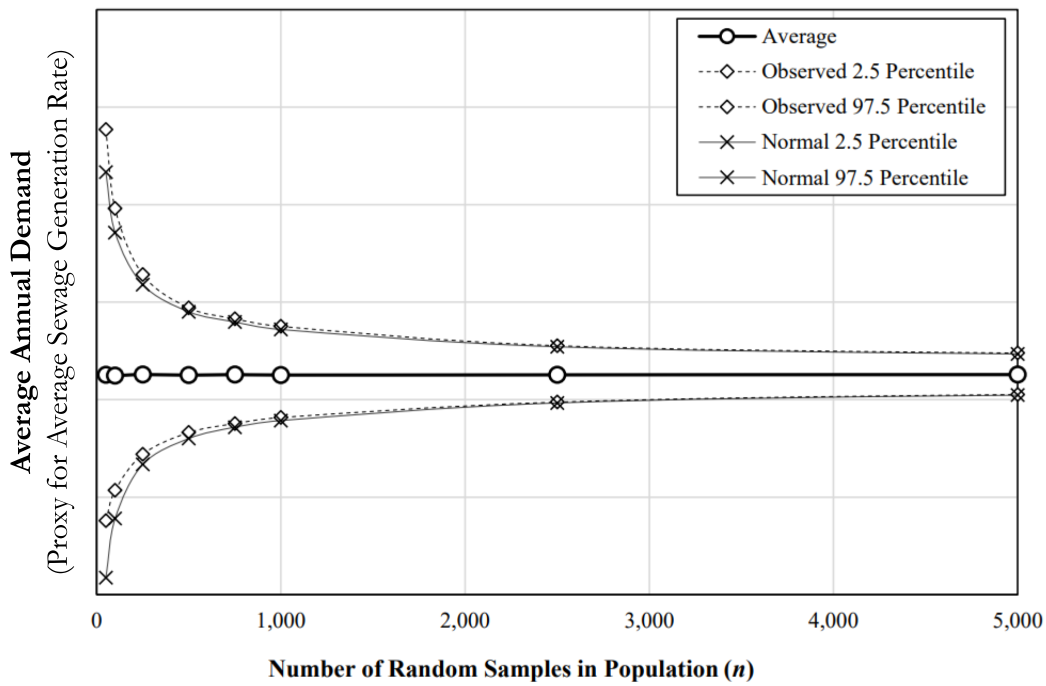


FIGURE 1: RESULTS OF BOOTSTRAPPING ANALYSIS
OF DAILY WATER CONSUMPTION DATA (JENKS, 2021)

## DESIGN FLOW COMPONENT ANALYSIS

In general, the estimation of design flows for sanitary sewers consists of estimates of the following parameters:

- Contributing population and area.
- Average daily sewage generation rate.
- Peaking factor (or diurnal pattern) applied to the average daily sewage generation rate.
- Extraneous flows, such as inflow and infiltration (I/I).

While design guidelines and criteria commonly include guidance on I/I rates to apply, flow monitoring data was available for the sewersheds tributary to the drop structure in question. This data was used to establish diurnal flow patterns as well as I/I response characteristics relevant to existing conditions and which are used in conjunction with the application of design storm patterns to produce the relevant hydraulic loading response for the sewer system. It is noted that considerable I/I was observed in the monitoring data. For future development conditions for which no monitoring data exists, it is common to apply a uniform design criterion based on contributing area.

For the drop structure in question, a calibrated hydraulic model was available and which facilitated analysis efforts. Several scenarios were simulated in order to assess the sensitivity of the resulting design flow estimate to the individual components contributing thereto. The generalized results of this process are summarized as follows (and ranked from most, to least, important):

- The I/I rate was the most influential design parameter, characterized as "extremely important" with a 95.8% range between design flow estimates across the scenarios assessed.
- The peaking factor (and/or application of diurnal curve) was identified as being "very important" with a 30.3-46.8% range between design flow estimates across the scenarios assessed.
- The average daily sewage generation rate was characterized as "important" with a 26.4% range in design flow estimates.
- The application of different design storm patterns (which also differed between York and Markham's criteria) for existing development produced a range in design flow estimates of 3.8-9.4% and, as such, was characterized as "modestly important."

Based on these results, an examination of each of the input parameters was undertaken, discussed in the next section.

## CRITICAL REVIEW OF DESIGN FLOW COMPONENTS

Each of the design flow components is reviewed in the order of importance presented above.

### Inflow & Infiltration (I/I)

Although I/I was clearly the most influential parameter based on the sensitivity analysis, a critical review was not necessary since a calibrated hydraulic model was applied for existing land uses which explicitly accounted for the monitored data. The application of the design criterion typically applied for future development was also not reviewed, noting that one of the study's recommendations emphasized the control and enforcement of construction standards relating to I/I control.

Nevertheless, any uncertainties relating to the foregoing were explicitly accounted for in formal uncertainty analyses performed for this study, discussed below.

**Peaking Factor**

A review of the diurnal patterns in York Region's calibrated hydraulic model revealed that the instantaneous peak-to-average flow ratio was in the order of 1.75 which, in turn, amounted to approximately 53% of what the Harmon formula would otherwise predict (i.e., 3.29). This result agrees well with findings from Ottawa where the peak-to-average flow ratio is commonly in the 0.4-0.6 times what the Harmon formula produces and, based on this, an adjustment factor of 0.8 times the Harmon formula is used by Ottawa (Ottawa, 2018). On this basis, a similar adjustment factor was applied for this project for any analyses using the "traditional" estimation method and for future developments in the hydrodynamic modelling. The diurnal curves in the calibrated hydraulic model were otherwise used for existing land uses.

**Average Daily Sewage Generation Rate**

A statistical analysis of a full year of residential customer water consumption data was undertaken and adjusted for household population densities based on Markham's then most recent Development Charges Background Study. Both city-wide and study (sewershed) area statistics were derived to understand consumption characteristics, noting that the study area is currently, and in the future is expected to be, comprised of predominantly residential land uses. Of course, water consumption is used here as a proxy for sewage generation. In some industry examples, a factor of 0.9 (i.e., 90%) or similar is applied to water consumption rates in order to estimate sewage generation rates, noting that some fraction of water consumption goes to outdoor water uses which does not get captured in the sanitary sewer system. For this work, a factor of 1.0 (i.e., 100%) was applied to lend a degree of conservatism to the analysis.

The results of this exercise produced overall average consumption rates that were more modest than the criteria applied by both York and Markham. More specifically, the measured average consumption rate was in the order of 83% of the criterion applied by York and 45% of the criterion applied by Markham. In and of themselves, these average values do not account for the effect of uncertainty which, as noted above, is a function of population size (i.e., scale). To account for this uncertainty, a root sum of squares method was applied which accounts for the uncertainty of each individual sample which is a function of the calculated standard deviation and applies it over the population size in question. This approach assumes that the data is in fact normally distributed (i.e., follows a Gaussian distribution) which, as noted earlier, is reasonable for such data. Based on the statistical characteristics derived from the analysis of consumption data and the population tributary to the drop structure in question, the aggregate uncertainty associated with the average consumption rate was less than 1%.

Accordingly, the average consumption rate (used as a proxy for the average sewage generation rate) could be comfortably applied. It is noted that, for purposes of the work, the actual average sewage generation rate applied was in the order of 25% higher than that measured in the statistical analysis, for reasons of conservatism, and which dwarfs the 1% uncertainty noted above.

## Design Storm Pattern

Different design storm patterns are applied by each of York and Markham and which produce different results. The pattern applied by York is not as "peaky" as that applied by Markham and, as such, produces a lower design flow estimate. York's pattern is anchored to a 4-hour storm duration with a 25-year frequency. On the other hand, Markham's Chicago-type design storm exhibits a common 25-year frequency across all durations.

To assess matters, both design storms were reviewed against recent rainfall statistics from the nearby Buttonville Airport weather station (ECCC, 2020). A 3-parameter intensity-duration-frequency (IDF) best-fit curve was plotted for various return periods with the results presented in Figure 2 along with the design storms applied by both York and Markham.

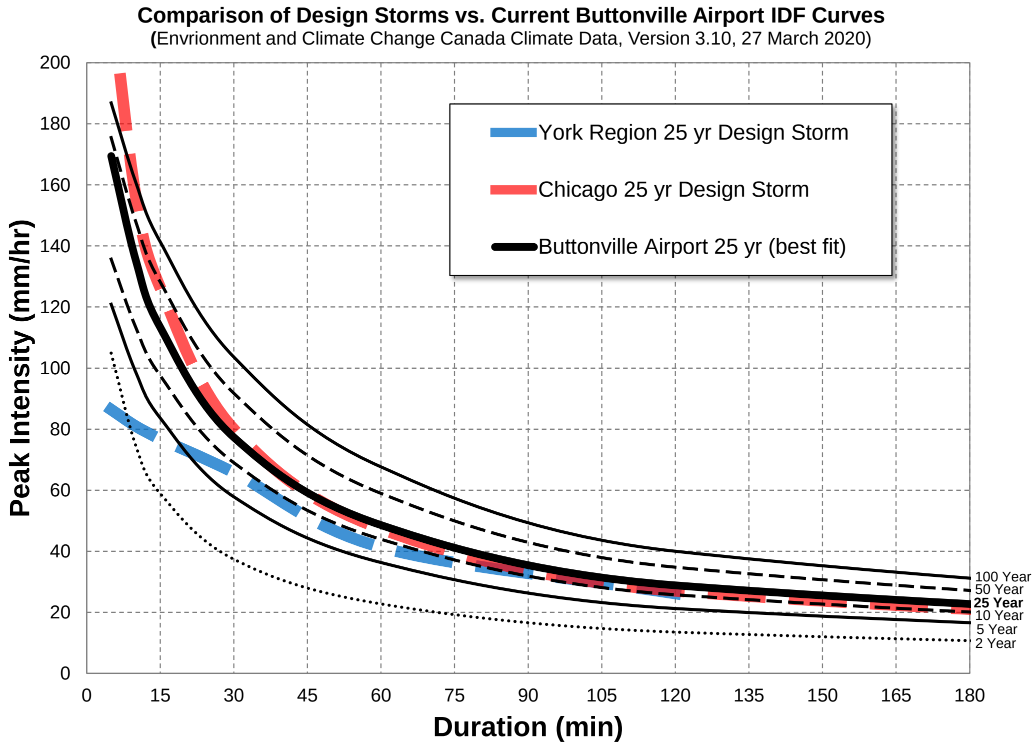


FIGURE 2: COMPARISON OF YORK AND MARKHAM DESIGN STORMS TO BUTTONVILLE AIRPORT IDF CURVES

These results indicate that the design storm typically applied by York, while appropriate for larger sewersheds where the time of concentration is in the order of 4 hours and which may be reasonable for certain region-scale infrastructure, would tend to underpredict rainfall intensities for smaller sewersheds as would be common for most local municipality applications. On the other hand, the design storm – more specifically, the IDF parameters – applied by Markham tend to produce higher intensities, particularly as rainfall durations get smaller. In fact, at a 5-minute duration, the Markham design storm (and the IDF parameters it employs) produces a rainfall intensity that is equivalent to an approximately 890-year return period based on the Buttonville Airport data (rather than the intended 25-year return period).

Fortunately, this particular parameter did not account for a significant difference in estimated design flow rates between York's and Markham's approaches (and was characterized as "modestly important" as noted earlier). To resolve this matter, Markham's (4-hour) Chicago-type design storm was used with the 25-year IDF parameters derived from the 2020 Buttonville data applied.

## UNCERTAINTY ANALYSIS

A formal uncertainty analysis was conducted using Monte Carlo Simulation (MCS) techniques whereby probability distributions characterizing input parameters are used to generate probability distributions of outputs – in this case, the design flow estimate. Such analyses provide a deeper understanding of both the range and likelihood of outcomes when compared to a single, deterministic value. Such an understanding is useful when assessing risk and, accordingly, is helpful with decision-making.

To apply the MCS method for this particular situation, the "traditional method" of sanitary sewage design flow estimation was applied, although its input parameters were informed by the calibrated hydrodynamic model so as to produce a comparable outcome. This allowed for the easy manipulation of input parameters using common spreadsheet software. The MCS method employs numerous "realizations" of the calculated result – 10,000 in this case – and for which each realization randomly samples from the probability distributions for each of the input parameters. From the resulting calculations (i.e., 10,000 estimates of the design flow), a statistical distribution was developed.

For each of the input parameters, a triangular probability distribution was applied, informed by the statistical representations and uncertainties associated with each input parameter. In practice, any number of probability distributions can be applied depending on the nature of the underlying data and statistics, as well as the degree of rigour required for the analysis. For this particular case, the application of triangular probability distributions struck an appropriate balance between the simplicity of the analysis and the fair representation of the underlying distributions.

The resulting probability distribution of the design flow estimate is provided in Figure 3. It demonstrates that there is indeed some uncertainty surrounding any single estimate of design flow and in both directions (i.e., under- and over-estimation). It also demonstrates the reasonable extent (range) thereof. Of particular note is that the design estimate determined when applying the local municipality's criteria is well outside of the practical range of the outcome distribution. In terms of decision-making based on this result, an understanding of the relationship between costs and design flow is also needed. For instance, if an upgrade is relatively affordable as is often the case if it involves a mere increase in the size of pipe whereby the incremental cost is low, then it may be sensible to simply do so (provided that no other performance characteristics are compromised). Also, if it is too costly or complicated to cover off all risks, such as at the right "tail" of the distribution, implementation of a "safe-fail" mechanism (i.e., whereby a failure is permitted to occur, but is allowed to do so in a safe manner) is often reasonable. In this particular case, the drop structure is permitted to overflow if flows beyond its designed capacity occur without resulting in problematic hydraulic conditions (e.g., upstream surcharging, spills to the surface, etc.).

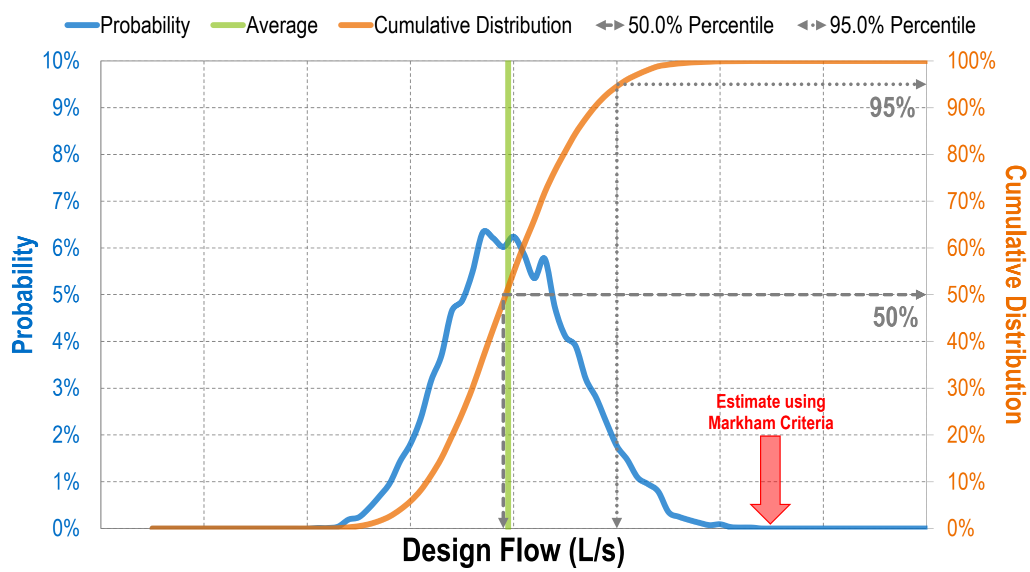


FIGURE 3: RESULTS FROM MONTE CARLO SIMULATION

## WHY IS THIS IMPORTANT?

As noted earlier, Ontario's infrastructure is facing the confluence of several important trends: (i) aging infrastructure; (ii) increasing intensification of urban areas; and (iii) increasing costs and complications of construction in urban environments. At the same time, recent advances in water efficiency, largely the result of changes in the Ontario Building Code (OBC), have resulted in the more moderate use of water. In contrast, commensurate changes in design criteria may not have kept pace with such improvements.

Whatever the case, as both the quantity and cost of infrastructure works grows, so too does the need to judiciously allocate financial resources. Infrastructure investment should be viewed through an economic lens whilst acknowledging the uncertainties inherent in the relevant input parameters and, in turn, the resulting design flow estimate. The increased application of field measurements, smart metering technology to capture consumption data and calibrated models will assist in developing statistical characterizations of the input parameters so as to be able to hone design criteria further to allow for an appropriate degree of conservatism. The increased use of statistical techniques based on first principles will further assist in the examination of selected infrastructure elements on a case-specific basis wherever warranted, as in the case of the sanitary sewer drop structure discussed herein. Further, such approaches can be applied for other infrastructure systems, such as water supply and distribution as well as storm drainage.

The reality is that the degree of variability in hydraulic loading is a function of scale and, as such, design criteria which do not appropriately account for such scale will result in potential over- or under-investment if the scale of a particular infrastructure element is outside of the reasonably applicable range of the criteria applied. As it relates to York and its nine local municipalities, it is intended that the application of approaches such as the one applied in this particular case will become increasingly considered so as to bridge the gap between potentially vastly different hydraulic loading estimates at jurisdictional boundaries. The underlying objective is to deliver a uniform and acceptable performance standard across these integrated systems using right-sized infrastructure (at the right cost).

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