# A Better Way to Model Storm Trunk Sewer Systems: Areal Distribution of Rain and Inlet Controls
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**Paper:** A Better Way to Model Storm Trunk Sewer Systems: Areal Distribution of Rain and Inlet Controls

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## Abstract

It recently became important to understand the actual capacity available in the 111 Avenue storm trunk system to service the Yellowhead Trail (YHT) freeway conversion project in Edmonton, Alberta. The City wanted to provide 1:100 year drainage servicing to the upgraded roadway, and was considering underground storage with controlled release to the trunk during the design event. Traditional trunk modelling, that assumes uniform application of the event over the entire trunk system catchment and does not account for flow restrictions at catch basin (CB) inlets, estimated zero capacity in the trunk at YHT, which would require 100% of the 1:100 year runoff to be stored. A study of discrete weather radar data of large events provided evidence that large events do not fall evenly over large areas. The highest intensity falls over small areas and intensity decreases with increasing distance from the centre of the event. In addition, CB inlets cannot pass 1:100 year runoff to sewers. A limited trunk model calibration effort demonstrated that the CB inlets within the 111 Avenue catchment actually pass peak flows close to the 1:2 year event. Application of an averaged areally distributed 1:100 year event centered on the project site, along with inclusion of 1:2 year inlet controls in the trunk model resulted in some available capacity within the trunk and a reduced storage requirement for the project roughly 1/3 of the total runoff volume. The resulting design concept is estimated to cost about $74 million. It could have been much more expensive.

# 1.0 Introduction

## 1.1 Two Key Trunk System Modelling Considerations

### ***No. 1 The Areal Distribution of Rain***

During large events you may have recognized that rain falls unevenly or at variable rates over large areas. It can be raining quite hard where you are, but not at all a few blocks away. Sometimes we get low intensity, long duration events that spread out over large areas, but even those are unevenly distributed. For the larger events, the variation in spatial distributions can be quite significant. We all experience this phenomenon when traveling or when talking about the event with friends. Should we go golfing at the course across the City when it's raining where we are?

Rain gauge and weather radar data proves it out – the adjacent sample weather radar image (Figure 1) shows the total amount of rain that fell over Edmonton on July 27, 2016. There appears to have been a fair amount of rain over a small area of central Edmonton, with less rain scattered around the City, and no rain at all for some areas.

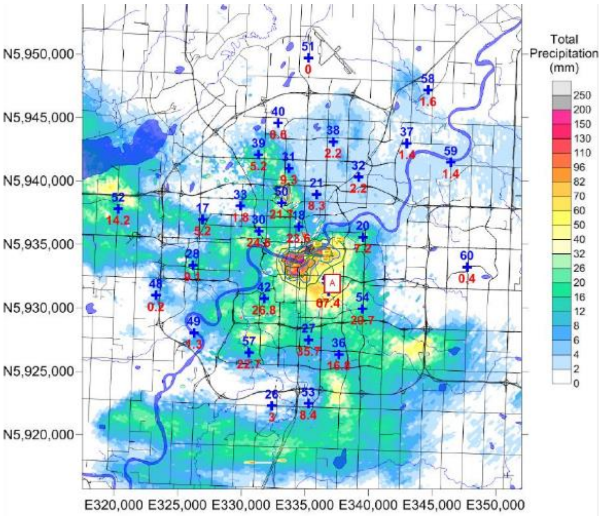


*Figure 1: Total Rain Over Edmonton on July 27, 2016*

Traditionally, computer simulation modellers apply 1:100 year rainfall design events evenly over entire large storm trunk system catchment areas. Is that approach truly representative of an actual statistical condition? Recalling the definition of a 1:100 year event being the chances of that event occurring at a single location, what should be considered a single location when the event is derived from rain data at a single rain gauge?

### ***No. 2 Catch Basin Inlet Controls***

*Figure 2: Typical Catch Basin Inlet*

In addition, we have seen water flowing down the streets during the peaks of large rain events and the only way for that water to get into the sewer system is through catch basin (CB) inlets. We need to recognize that CB inlets have limited capacities and large runoff flows are not necessarily able to pass through the small grates on the CBs unobstructed. During large events, some of the runoff may pond over CBs or flow to the next CB until capacity becomes available.

Traditionally, computer simulation modellers route 1:100 year runoff directly to sewer without any inlet capacity restrictions. Recognizing that inlets have limited capacities, is that approach truly representative of actual conditions?

## 1.2 Why Do These Two Trunk System Modelling Considerations Matter?

Inner city redevelopment projects occur all the time. Since the older drainage systems were not originally designed to manage runoff from extreme events like the 1:100 year, most inner city projects in Edmonton are required to control their site runoff from the 1:100 year event as a means of protecting downstream under-designed municipal drainage systems from flooding. Linear municipal infrastructure projects, including roadways and LRT, also typically have a design goal of providing 1:100 year level of service for their new infrastructure – meaning no flooding on the roadway or track during a 1:100 year event. To achieve this goal, storage is typically required with controlled release to the nearby existing sewer system. As a result, it becomes critically important to know how much can be released to the local storm sewer system during the 1:100 year design event – how much downstream capacity would actually be available? As we know, storage = inflow – outflow. So, if outflow is conservatively estimated to be zero, then all inflow must be stored. But if there were to be significant downstream capacity available during the design event (outflow >>0), then the storage requirement, and therefore cost to the project, may be significantly reduced.

It recently became important to understand the actual capacity available in the 111 Avenue storm trunk system in Edmonton, Alberta during a 1:100 year design event to service the Yellowhead Trail (YHT): St. Albert Trail to 97 Street project (the ‘project’). This project was the largest and most complex project within the City’s Yellowhead Trail Freeway Conversion Program. The City of Edmonton (the City) wanted to provide 1:100 year drainage servicing within the project area, and was considering underground storage with controlled release to the trunk during the design event. The approval authority, responsible for managing and maintaining the drainage systems in Edmonton, initially identified that their trunk system modelling indicated that there would be no available capacity in the downstream trunk during the 1:100 year design event. All site inflows during that event would need to be stored. Their trunk modelling was based on traditional approaches of uniform application of the 1:100 year rainfall over the entire trunk catchment area without any inlet restrictions.

The design team then proceeded to work closely with the approval authority, and ultimate owner of the drainage infrastructure, to explore ways of more accurately estimating trunk capacity during the 1:100 year design event by incorporating the above two previously discussed phenomena in the design. This paper describes the trunk system modelling approaches developed for the project that led to an understanding that there would be an estimated 6.5 $m^3/s$ of available trunk sewer capacity during the 1:100 year event – a very significant capacity. This resulted in a design storage requirement of about 7,000 $m^3$. Inflows were estimated to be about three times greater than the 7,000 $m^3$, meaning that if there were zero discharge available during the event, the storage elements would have needed to be designed to be about three times bigger than the current design.

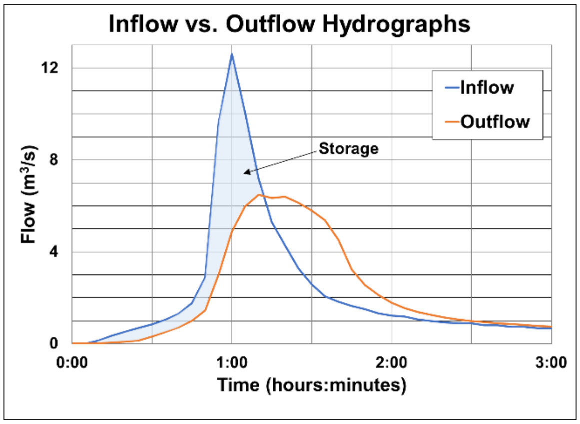


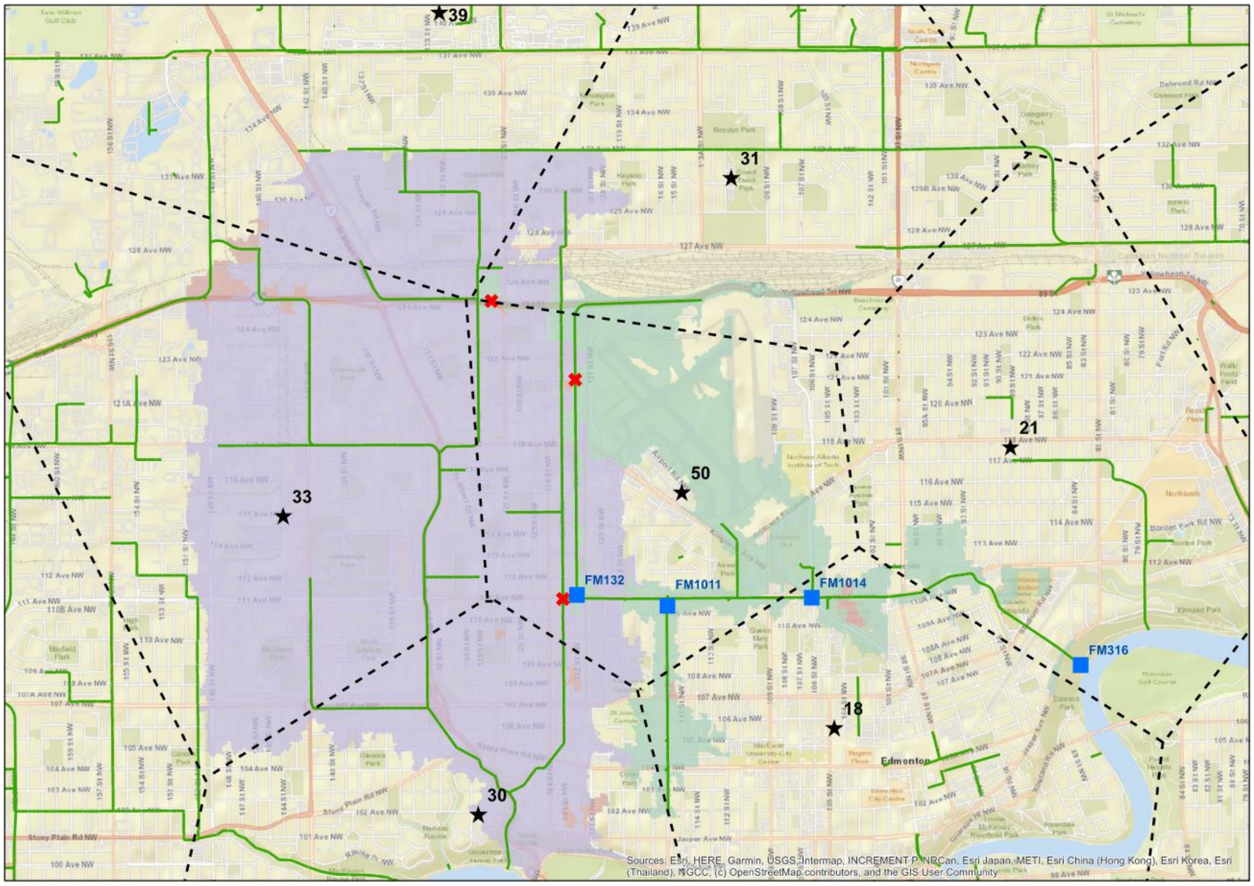
***Figure 3: Storage = Inflow – Outflow***

The subsequent conceptual engineering design for the 7,000 $m^3$ storage element was estimated to cost about $74 million. A cost estimate for the initial scenario of zero during-event discharge was not developed. However, it can be concluded that had the revised trunk system modelling approach not been developed, the storage cost would have been much, much greater than $74 million.

## 2.0 Catch Basin Inlet Controls

Inner city CB inlets were installed many decades ago. They are typically regularly spaced and located at roadway intersections and sag locations for purposes of providing positive drainage from the surface to the local storm or combined sewer. The capacities of the CB inlets to convey design flows to the local sewers were most likely not calculated or confirmed at the time of installation.

Studies have subsequently been undertaken to develop rating curves (inflow vs water depth) for various standard CB inlet configurations, that indicate an increase in capacity with increased head. However, for the Yellowhead Trail: St. Albert Trail to 97 Street project, overall trunk flows during a large event needed to be estimated, and careful consideration of each CB and its head conditions within the trunk system catchment area could not be made. Fortunately, some limited trunk sewer flow monitoring and corresponding local rain gauge data was available. From this data, about a 1:25 year event was measured at the local rain gauges and corresponding flows were recorded at the sewer flow monitor FM132 (shown on the following figure) located on the trunk at 111 Ave and 122 St, monitoring about the upper 1/3 of the total trunk system catchment (shaded in green). A 1:25 year event was considered large enough to test the capacities of the CB inlets on an overall catchment wide basis, so a limited model calibration effort was undertaken.



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

***Figure 4: 111 Avenue Storm Trunk, Catchment Area, Sewer Flow Monitors and Local Rain Gauges***

A discretized computer simulation model of the 111 Avenue storm trunk sewer system was made available to the design team by the approval authority. The model had been previously calibrated to various smaller storm events, so was considered calibrated by the design team, other than accounting for CB inlet controls. The model was a 1D representation of the system.

The design team proceeded to add CB inlet controls into the trunk model by specifying a maximum inflow at the nodes, then applied the rain data from August 29 – 30, 2013 from the local rain gauges using the Thiessen Polygon approach.

The limited model calibration results are shown on Figure 5, with sewer monitored flows indicated by the black dashed line and model estimated flows indicated by the solid-coloured lines. As there was a time lag discrepancy between monitored and modelled flows, the monitored flows were adjusted/lagged by 1 hour and are shown on the figure by the light blue dashed line to provide a better comparison to the modelled flows. The 1 hour routing delay may be related to model routing or an error in the time recording of the sewer monitor, but the reasons behind the delay were not investigated further.

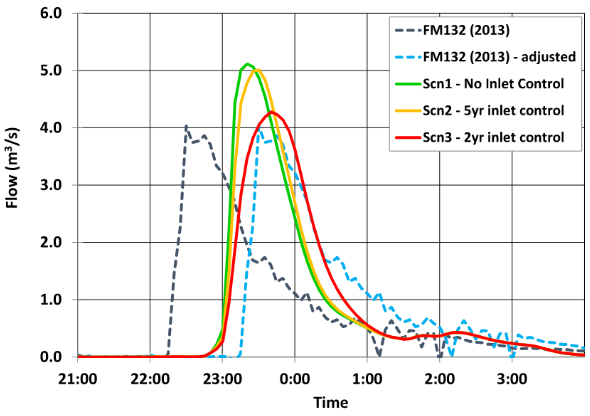


***Figure 5: Model Calibration – 29-30 Aug 2013***

The results show that the flows in the sewer predicted by the model did not match the flows monitored in the sewer for the condition of no inlet controls (Scenario 1 on figure). When the inlets were set to a 1:5 year capacity – by limiting maximum inflow to sewer to the peak runoff rates during a 1:5 year event (Scenario 2) – there was very little change in predicted flows. However, when CB inlet capacity was set to a 1:2 year capacity (Scenario 3), peak flows predicted by the model dropped to be very close to peak flows monitored in the sewer. This relative matching of peak flows indicated to the design team that, on a gross, catchment-wide basis, the CB inlets appear to be limiting peak flow to sewer to flows roughly equivalent to runoff from a 1:2 year event.

The event that occurred on August 29-30, 2013 was large enough over the catchment area upstream of sewer flow monitor FM132 to test the conveyance capacities of the inlets and allow for a limited model calibration to approximate their capacities. As a result, this limited model calibration effort provided a strong indication that the CB inlets within the trunk catchment area were limiting flow to sewer to rates in the order of a 1:2 year event.

## 3.0 Approach to Modelling the Areal Distribution of Design Storms

### 3.1 The Edmonton Study

As part of the relevant background information to the project, the approval authority provided the following suite of four papers that were prepared for the Canadian Meteorological and Oceanographic Society (CMOS) in 2013 by the consultant company Kije Sipi Ltd – RadHyPS Inc (Kije Sipi) for the City of Edmonton's Drainage Services branch, and published in editions of the *CMOS Bulletin SCMO*:

*Spatial-Temporal Rainfall Storm Characteristics:*

- Part I: Building a Rainfall Storm Database
- Part II: General Storm Characteristics
- Part III: Areal Reduction Factors
- Part IV: Alternate Design Storm Method

The purpose of the Edmonton Study was to develop theoretical watershed design storms that recognize and represent the areal distribution of rain patterns and account for climate change, storm durations and storm movement behaviour over time. It was recognized that uniformly applying point based (rain gauge) data over an entire watershed results in a gross volumetric overestimation of ground level rainfall, since actual rain patterns do not distribute evenly over large areas. It was also recognized that due to the lengthy distances between rain gauges and the highly variable spatial distribution of rain events, rain gauges rarely record the maximum rain, or peak storm cell that occurs. As a result, rain gauge statistics tend to underestimate peak rain volumes from events and overestimate average rain volumes over catchment areas. The study analyzed weather radar data and proposed an alternate storm method for water resource engineers to use to develop the designs of costly water related infrastructure that are not overly conservative and better reflect actual rain patterns.

The Edmonton Study considered 11 years of weather radar data (1998 - 2009) from the Carvel federal weather radar station located west of the City of Edmonton. The weather radar data covered an area of about 22,250 km$^2$, including the City of Edmonton and surrounding areas. All data within the 22,250 km$^2$ Edmonton area was considered to have a "homogeneous hydrometeorological regime", hence all rainfall characteristics within this area were deemed part of the same data population. The radar data includes specific rainfall data (e.g., rainfall intensity, volume, etc.) at 1-minute time increments for each 1 km$^2$ grid area (22,250 grid data points compiled at 1 minute intervals). Data was collected from about 25,500 storm events through the 11-year period. The study recommended that as additional years of data become available, that the analysis be updated to include the additional data.

About 500 storms from the 25,500 storm dataset were randomly selected for development of Areal Reduction Factors (ARFs). The 500 storms included a mix of all sizes of storms, including small, medium and large events. ARFs characterize the spatial reduction of the average storm rainfall depth at distances extending radially from the storm maxima. The storm maxima is assigned an ARF = 1.0, locations at a distance from the maxima where the rain intensity measures 90% of the storm maxima are assigned an ARF = 0.9, etc.

The ARF patterns for each of the 500 events were measured from the weather radar data with the distances from center of each event to reducing ARF values measured in all directions and the contours plotted. The results from the normalized 500 storm events were then averaged and plotted, with contours at 0.1 ARF increments – see Figure 6. It can be observed that while the average unitized areas for each 0.1 ARF increment are somewhat irregularly shaped, likely due to prevailing west to east wind conditions, they can be approximately represented by concentric circles.

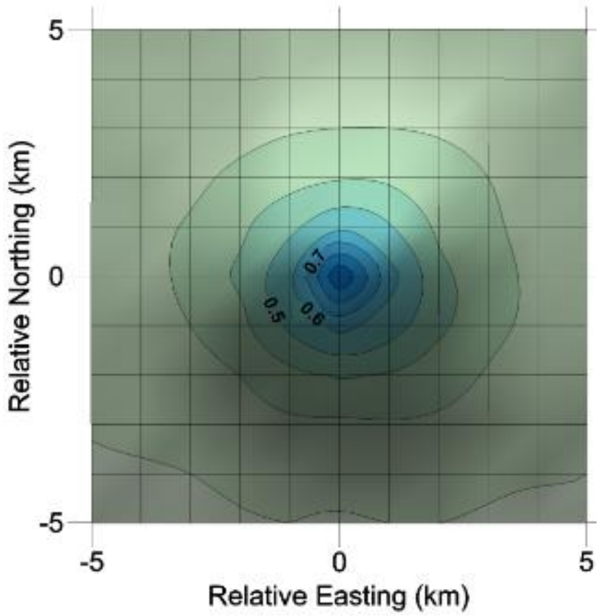


***Figure 6: Average Unitized Areal Distribution of Rain (500 Random Storms)***

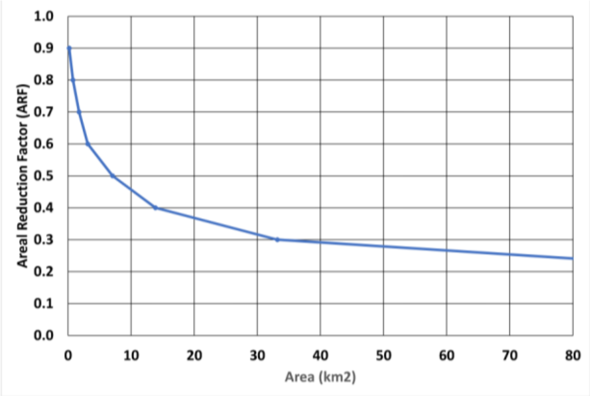


***Figure 7: Average Unitized Areal Distribution of Rain***

The design team considered the average normalized ARF rain distribution presented in the Edmonton Study with a view to developing a trunk sewer system modelling approach. To that end, the design team considered the above plot and then estimated the areas of each ARF increment contour from the averaged plot, and created the X-Y chart shown on Figure 7, as another way to represent the same information. The plot represents the reduction in average ARF values over concentric circular areas centered over the project site. The results show how the peak of the averaged storms (ARF = 1.0) drops precipitously with distance from the center of the events, with the ARF reaching 0.50 at areas of about 7 km$^2$, and ARF reaching 0.25 at areas of about 75 km$^2$.

### 3.2 Development of the Areally Distributed Design Event Condition

Through discussions with the approval authority, it was recognized that while there appeared to be promise in the use of the above approach developed from the Edmonton Study in developing a trunk system modelling approach, the data that was used in the Edmonton Study included data from all types of storm events. As the intent of the project was to develop an understanding of the areal distribution of typical short duration flood events in Edmonton, it was concluded that the Edmonton Study data did not necessarily meet this goal. It was then agreed that it would be more representative if a similar analysis could be conducted of rain events closer in duration and magnitude to the project design event (i.e., the 1:100 year, 4 Hour Chicago event).

To that end, Kije Sipi was engaged to mine the original data set of 25,500 events from the years 1998 through 2009, select only larger events of short duration, and repeat the same ARF unitizing, averaging process that they developed for the original Edmonton Study. While several data sets were developed and analyzed, the data set selected for the project by the approval authority included:

- only events of durations between 3.5 hours to 4.5 hours; and
- only events with total rain volumes of 45 mm and larger (45 mm is roughly equivalent to a 1:5 year design event).

189 storm cells were found from the 25,500 event database that met the above criteria.

Each of the 189 short duration flood events were normalized with Areal Reduction Factors (ARFs) developed at 1 km$^2$ grid spacing, then aligned on center with the values in each 1 km$^2$ grid averaged. The results of the assessment are presented in tabular format and plotted in plan view on Figure 8.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | 0.42 | 0.44 | 0.44 | 0.39 | 0.38 | - | - | - | - |
| - | - | - | 0.43 | 0.43 | 0.45 | 0.44 | 0.39 | 0.40 | 0.41 | - | - | - |
| - | - | 0.44 | 0.45 | 0.47 | 0.44 | 0.45 | 0.44 | 0.44 | 0.41 | 0.44 | - | - |
| - | 0.46 | 0.44 | 0.47 | 0.44 | 0.51 | 0.50 | 0.49 | 0.46 | 0.50 | 0.44 | 0.44 | - |
| - | 0.47 | 0.48 | 0.44 | 0.52 | 0.59 | 0.61 | 0.59 | 0.50 | 0.45 | 0.45 | 0.43 | - |
| - | 0.47 | 0.46 | 0.45 | 0.55 | 0.64 | **1.00** | 0.68 | 0.53 | 0.48 | 0.43 | 0.40 | - |
| - | 0.41 | 0.46 | 0.46 | 0.54 | 0.61 | 0.69 | 0.63 | 0.54 | 0.49 | 0.43 | 0.39 | - |
| - | 0.41 | 0.43 | 0.45 | 0.49 | 0.53 | 0.53 | 0.53 | 0.50 | 0.46 | 0.43 | 0.41 | - |
| - | - | 0.41 | 0.44 | 0.48 | 0.47 | 0.47 | 0.45 | 0.41 | 0.42 | 0.42 | - | - |
| - | - | - | 0.41 | 0.41 | 0.43 | 0.42 | 0.41 | 0.40 | 0.37 | - | - | - |
| - | - | - | - | 0.36 | 0.36 | 0.36 | 0.36 | 0.35 | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - |

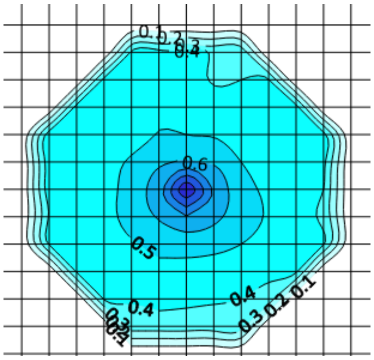


*Figure 8: Areal Distribution of 189 Flood Events – 3.5 hr to 4.5 hr, Greater than 45 mm*

The above results became the average normalized areal distribution of short duration, large events in Edmonton that was accepted by the approval authority for use in the development of a trunk system modelling approach for the project. The design team then interpreted the above distribution to develop the adjacent X-Y chart (Figure 9) of intensity reductions with increasing concentric circles from the center of the event, as another way to approximately represent the same information. It can be observed that this distribution of short duration, large events is more conservative than the original distribution of random events from the Edmonton Study. That is, rainfall is reduced from peak intensity to a lesser degree for areas further from the center of the event.

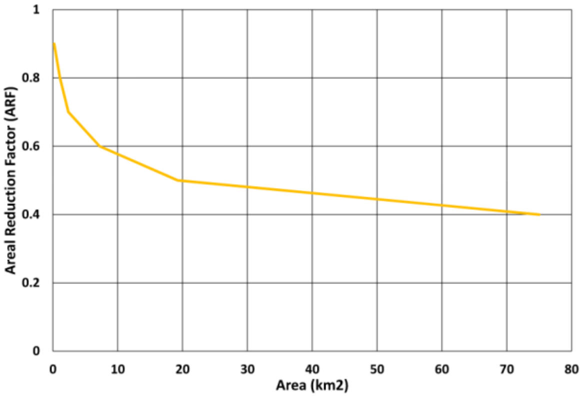


*Figure 9: Areal Distribution of Rain – Short Duration Flood Events*

### 3.3 Proposed Modelling Approach

The challenge for the design team then became to develop a trunk system modelling approach where rainfall is distributed over large areas in the model in a manner that approximately reflects the areal distribution curve in the above figure (Figure 9). The distributions would be unique for each design event. That is, the 1:100 year distribution would be somewhat different than the 1:50 year distribution, etc. As well, as it is quite often necessary to model a suite of design events on projects, a means of reducing modelling effort when switching between design storm assessments was also desired.

To meet these goals, it was decided that it would be beneficial to assign different design events to areas beyond the center, as compared to assigning portions of a single design storm, where possible. To that end, the ARF values of different design events in relation to the primary design storm needed to be calculated. The results are presented in the following table.

***Table 1: Design Storm ARF Values***

| **Design Storm** | **Total Rain (mm)** | **ARF Values for Design Scenarios** | | | | | |
|---|---|---|---|---|---|---|---|
| | | **1:100 yr** | **1:50 yr** | **1:25 yr** | **1:10 yr** | **1:5 yr** | **1:2 yr** |
| 1:100 yr | 80.4 | 1.00 | | | | | |
| 1:50 yr | 67.2 | 0.84 | 1.00 | | | | |
| 1:25 yr | 56.0 | 0.70 | 0.83 | 1.00 | | | |
| 1:10 yr | 44.0 | 0.55 | 0.65 | 0.79 | 1.00 | | |
| 1:5 yr | 35.8 | 0.46 | 0.53 | 0.64 | 0.81 | 1.00 | |
| 1:2 yr | 24.9 | 0.31 | 0.37 | 0.44 | 0.57 | 0.70 | 1.00 |

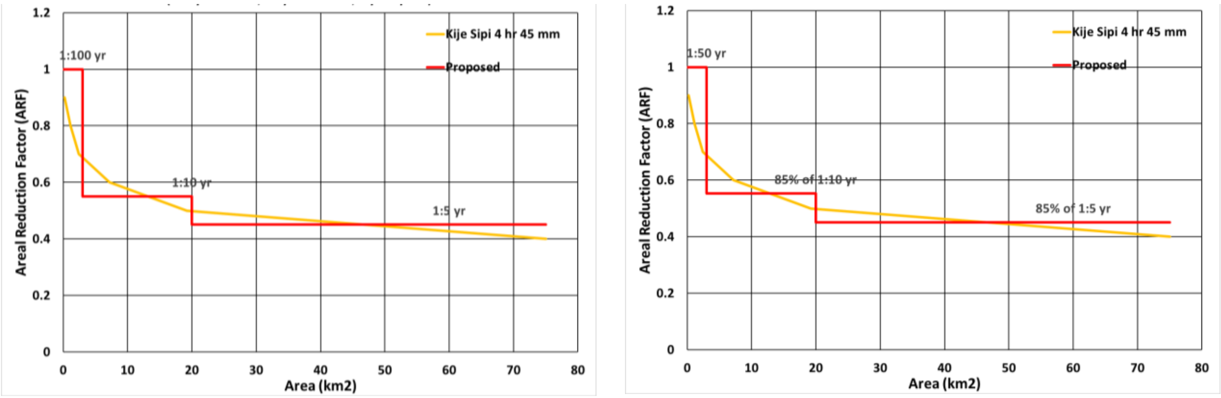
Note: Data are for 4-hour, Chicago design events

A careful consideration of the distribution to be approximated (Figure 9), indicated the potential to approximate three different zones that would be common to all design storm scenarios for ease of modelling:

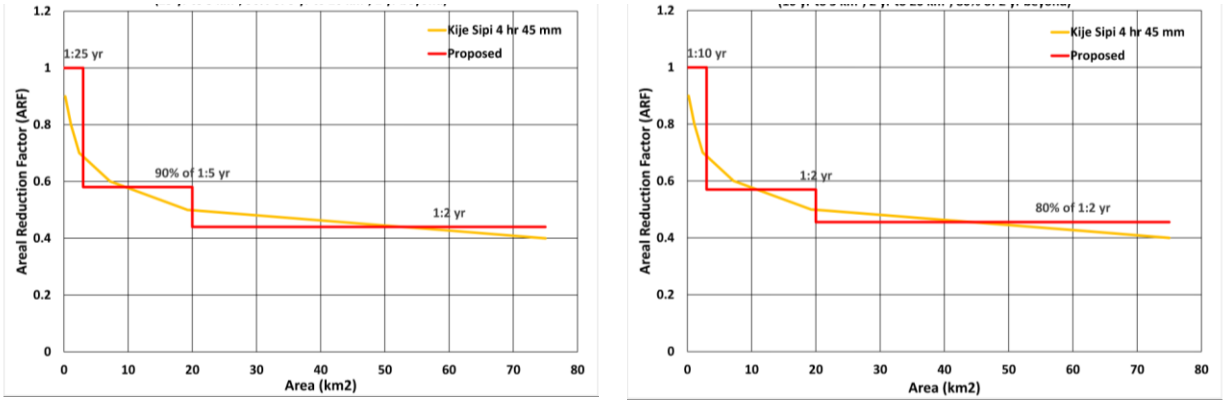
- a central, smaller zone where the curve is quite steep;
- a 2nd zone around the central zone where the curve changes slope the most; and
- a 3rd zone around the 2nd zone where the slope of the curve is quite gradual.

To make a reasonable fit to the curve, it was concluded that the central zone would involve a concentric circle of 3 km$^2$ (radius = about 1 km), and the 2nd zone would involve a concentric circle of 20 km$^2$ (radius = about 2.5 km). The 3rd zone would be all areas beyond the 20 km$^2$ concentric circle. It was also decided that to reduce modelling effort, the three zone sizes would remain consistent between design event scenarios.

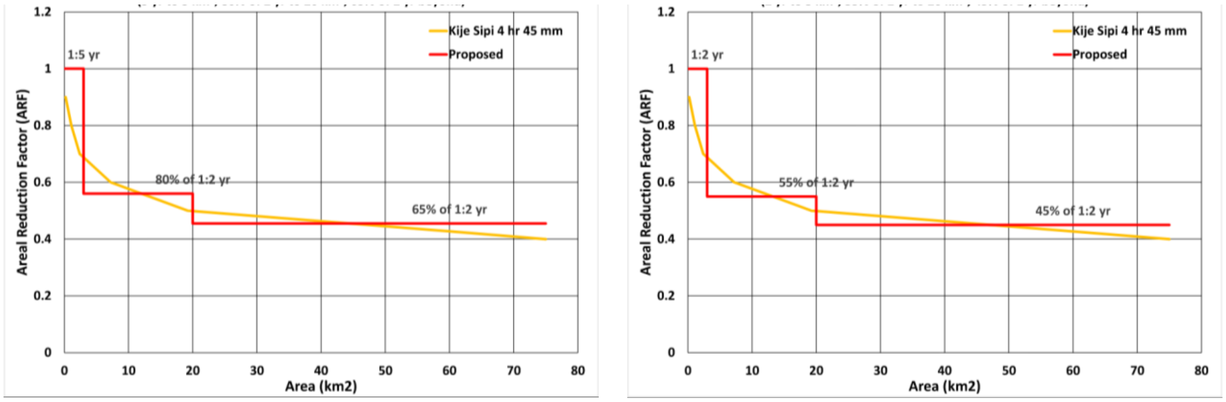
The above considerations led to the development of a trunk system modelling approach that was used to assess system performance for each design event condition, as shown on the following group of charts in Figure 10.



**1:100 Year Distribution** **1:50 Year Distribution**



**1:25 Year Distribution** **1:10 Year Distribution**



**1:5 Year Distribution** **1:2 Year Distribution**

***Figure 10: Areal Distribution of Design Storms – Proposed Modelling Approach***

When modelling the trunk system for how it would perform near the project site during a 1:100 year design event, the following was applied:

- the 1:100 year design storm over sub-catchment areas roughly located within a 3 km$^2$ circle centered on the project site;
- the 1:10 year design event over sub-catchment areas roughly located beyond the 3 km$^2$ central circle, over areas out to a 20 km$^2$ concentrically located circle; and

- the 1:5 year design storm over all trunk system sub-catchment areas located beyond the 20 km$^2$ concentrically located circle.

Similarly, when modelling how the trunk system might perform during a 1:50 year event, the 1:50 year design storm was applied over the project site out to an area of 3 km$^2$, 85% of the 1:10 year design event was applied out to 20 km$^2$, and 85% of the 1:5 year was applied beyond 20 km$^2$. The methodology is similar when studying the impacts of other design events, as shown graphically on Figure 9 and provided in the following table.

***Table 2: Areal Distribution of Design Storms – Proposed Modelling Approach***

| **Design Scenario** | **Design Events to be Distributed Over the Following Areas** | | |
|---|---|---|---|
| | **Areas within 3 km$^2$** | **Areas Between 3 and 20 km$^2$** | **Areas Beyond 20 km$^2$** |
| 1:100 yr | 1:100 y | 1:10 yr | 1:5 yr |
| 1:50 yr | 1:50 yr | 85% of 1:10 yr | 85% of 1:5 yr |
| 1:25 yr | 1:25 yr | 90% of 1:5 yr | 1:2 yr |
| 1:10 yr | 1:10 yr | 1:2 yr | 80% of 1:2 yr |
| 1:5 yr | 1:5 yr | 80% of 1:2 yr | 65% of 1:2 yr |
| 1:2 yr | 1:2 yr | 55% of 1:2 yr | 45% of 1:2 yr |

Note: These values are valid for 4-hour, Chicago design events only.

### 3.4 Qualifications

***Worst-Case Conditions for Design***

The above approach assumes that the worst-case conditions within the trunk system at the project site are when the storm is centered over the project site. While this may typically be the case, it is advised to confirm worst case design conditions by testing alternate scenarios, including a scenario where the design storms are centered upstream along the trunk system from the project site, and another with the design storms centered downstream along the trunk system. This sensitivity testing can then account for the impacts of how storms move through an area and confirm worst case conditions for design.

***Approach Only for 4 Hour Chicago Distribution***

This approach was developed for the 4-hour Chicago storm distribution as that distribution governs over the 24-hour Huff distribution when assessing trunk system conveyance capacities. Should there be a project need to consider the 24-hour Huff distribution, the areal distribution of rain for short duration flood events developed for this project from statistical analysis of discrete weather radar data, and the subsequent computer modelling approach developed from this data would not be representative. For those circumstances, it is recommended that the original weather radar data set of 25,500 discrete events be mined for long duration (24-hour) flood events and the above-described assessment process repeated to develop the most representative modelling approach for long duration flood events.

## 4.0 Application

Development of this ground-breaking trunk system modelling approach was not an academic exercise. It was driven by a practical design need, a strong belief that traditional trunk system modelling was grossly over-conservative and that very large capital costs were on the line. For the YHT project, the 1:100 year design storm was applied over the project site and the existing trunk catchment areas within the 3 km$^2$ concentric circle centered over the site as shown on the following figure. The 1:10 year design storm was then applied in the model to sub-catchment areas outside the 3 km$^2$ circle, extending out to the 20 km$^2$ circle shown on the figure. Lastly, the 1:5 year design storm was applied to areas beyond the 20 km$^2$

circle. Catch basin inlet controls were added to the model and each inlet was sized to pass runoff equivalent to runoff estimated from application of a 1:2 year design event.

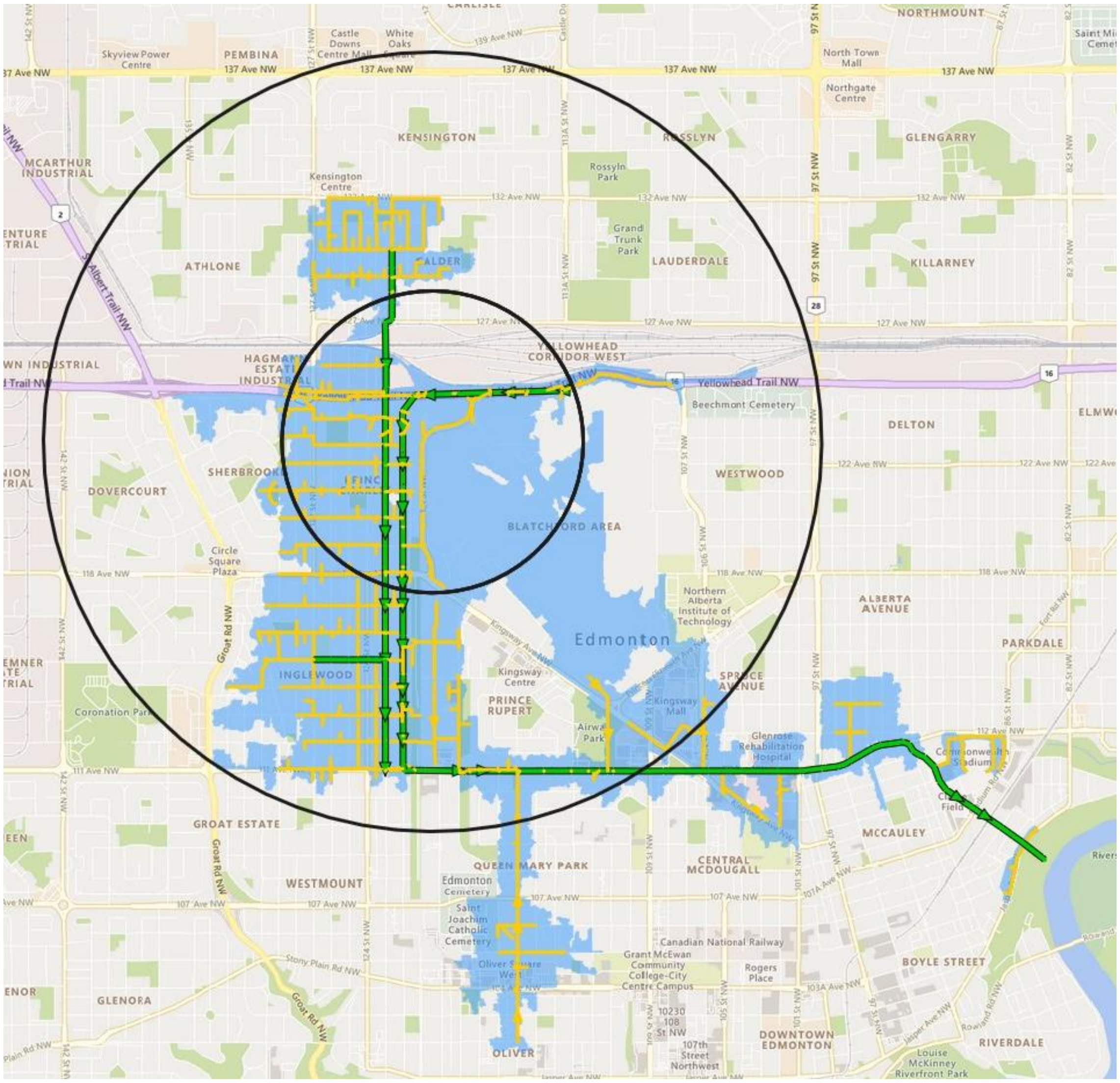


***Figure 11: Application of Areal Rain Distribution on 111 Avenue Storm Trunk System***

Modelling was then undertaken to include a storage device installed to control runoff from the project site into the existing deep trunk. The outlet rate of the storage device was adjusted upwards until a maximum surcharge level was shown to occur in the existing trunk in which a free outfall condition from the proposed storage could still be maintained. The results of the analysis are shown on the following figure (Figure 12).

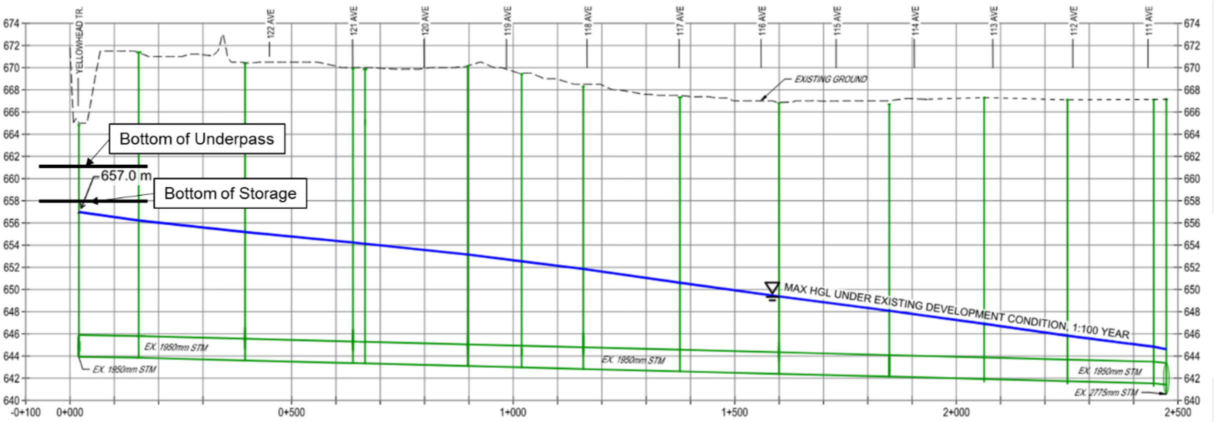


*Figure 12: 111 Avenue Storm Trunk System Surcharge*

These results show the profile of the upstream end of the 111 Avenue storm trunk system that runs south along 122 Street. The project site and storage element are located at the upstream end – on the left side of the profile. The Hydraulic Gradeline (HGL) shown on Figure 12 is what might be expected to occur within the trunk system during a 1:100 year event centered on the project site with the storage element releasing at a maximum rate of 6.5 m$^3$/s. At that rate it can be observed that the HGL would rise quite high above the deep trunk system but remain at a depth in which storage elements could be designed to discharge in free-outfall conditions during the peak – it was important that the trunk would not backup into the storage element as it would have a negative impact on storage sizing. The resulting design storage requirement is 7,000 m$^3$.

The resulting storage design concept consists of a conveyance/storage tunnel about 1,350 m long and 2,600 mm inside diameter, as shown on the following drawing, complete with service connections, access manholes, outlet controls and oil/grit separators, all at an estimated capital cost of about $74 million.

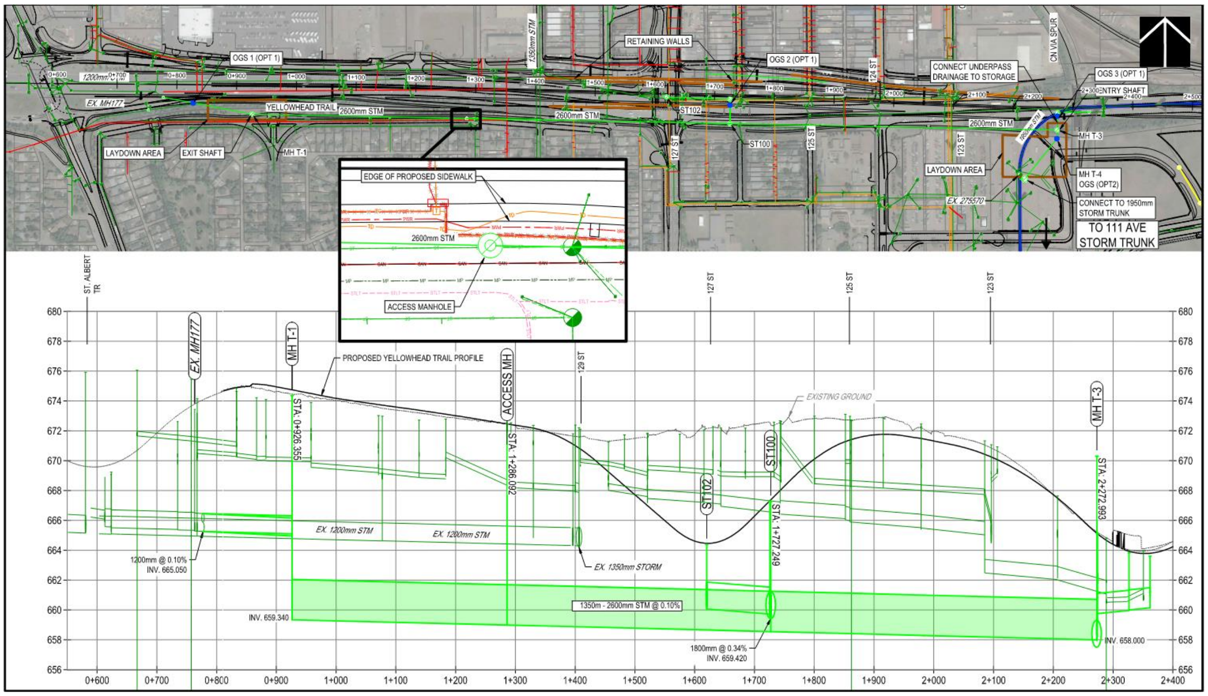


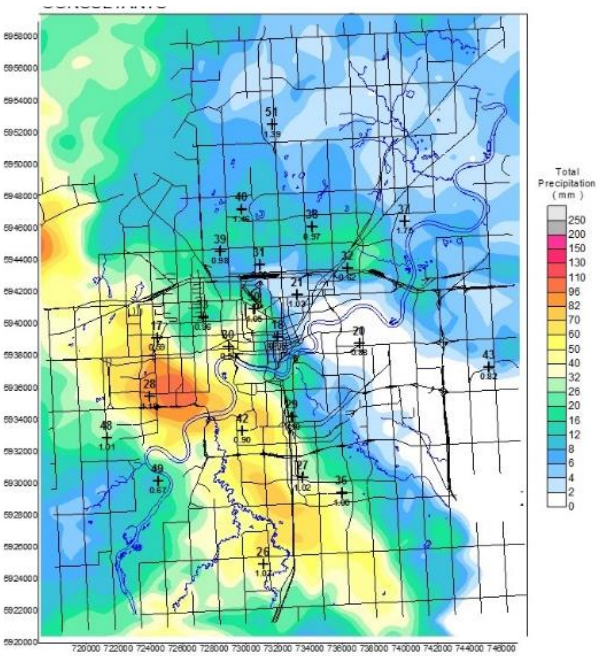
*Figure 13: Plan/Profile of Proposed Conveyance/Storage Tunnel*

As demonstrated on Figure 3 earlier in this paper, the resulting storage of 7,000 $m^3$ depended heavily on the ability to release at a maximum rate of 6.5 $m^3/s$ during the design event. Should the allowable release rate have been determined to be any lower, the required storage volume and associated cost would have been significantly greater.

## 5.0 Conclusions

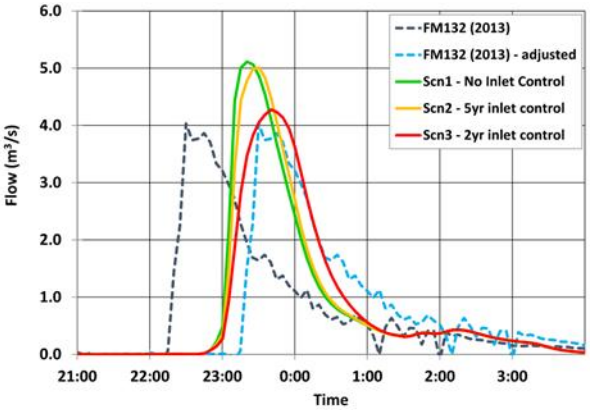
### #1) Rain Doesn't Fall Evenly Over Large Areas

As evident from weather radar data, rain does not fall evenly over large areas. Applying rain gauge derived design storms uniformly over large areas when modelling trunk systems does not represent an actual statistical condition.



### #2) Catch Basin Inlets Have Limited Capacity

Catch basin inlets have limited capacity to pass surface runoff to the sewer system. Inlet capacity is restricted by the grate openings and varies based on head condition above the grates. Inlets on older drainage systems were not designed to pass major event runoff to the sewer system.



### #3) Limited Model Calibration Can Provide an Estimate of Inlet Capacity

Limited trunk system model calibration to a large event can help to estimate system wide CB inlet capacities. For the YHT project, CB inlet capacities on a trunk catchment wide basis, were grossly estimated to pass runoff equivalent to a 1:2 year event. Runoff from a 1:2 year event will be very much less than runoff from a 1:100 year event, so the traditional model assumption that 1:100 year runoff can route directly to sewer, should be considered grossly inaccurate when modelling sewer systems.

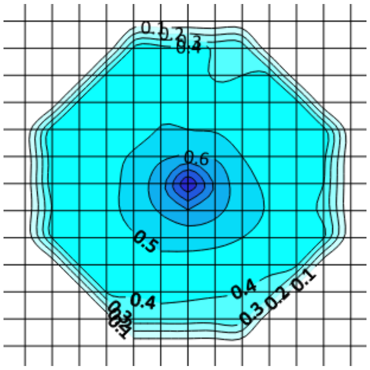
## #4) Weather Radar Data Can be Used to Estimate An Averaged Areal Distribution of Rains

Weather radar data can be analyzed to estimate an average areal distribution of rain using Areal Reduction Factors (ARF). The analysis can be summarized in the following steps:

- collect weather radar data (in 1 km$^2$ grid);
- select rain events that meet desired criteria;
- normalize events by assigning ARF to datapoints on the grid, with 1.0 being the maxima of each event; and
- line up the events by placing ARF of 1.0 in the center and calculate an average ARF for each grid;

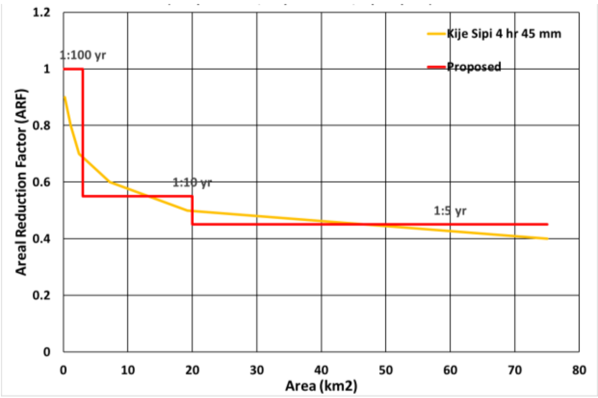
The analysis generates an ARF matrix that can be presented in different ways, including a matrix and contour plot, as shown below.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | - | - | - | - | - | - | - | - | - | - | - |
| - | - | - | - | 0.42 | 0.44 | 0.44 | 0.39 | 0.38 | - | - | - | - |
| - | - | - | 0.43 | 0.43 | 0.45 | 0.44 | 0.39 | 0.40 | 0.41 | - | - | - |
| - | - | 0.44 | 0.45 | 0.47 | 0.44 | 0.45 | 0.44 | 0.44 | 0.41 | 0.44 | - | - |
| - | 0.46 | 0.44 | 0.47 | 0.44 | 0.51 | 0.50 | 0.49 | 0.46 | 0.50 | 0.44 | 0.44 | - |
| - | 0.47 | 0.48 | 0.44 | 0.52 | 0.59 | 0.61 | 0.59 | 0.50 | 0.45 | 0.45 | 0.43 | - |
| - | 0.47 | 0.46 | 0.45 | 0.55 | 0.64 | **1.00** | 0.68 | 0.53 | 0.48 | 0.43 | 0.40 | - |
| - | 0.41 | 0.46 | 0.46 | 0.54 | 0.61 | 0.69 | 0.63 | 0.54 | 0.49 | 0.43 | 0.39 | - |
| - | 0.41 | 0.43 | 0.45 | 0.49 | 0.53 | 0.53 | 0.53 | 0.50 | 0.46 | 0.43 | 0.41 | - |
| - | - | 0.41 | 0.44 | 0.48 | 0.47 | 0.47 | 0.45 | 0.41 | 0.42 | 0.42 | - | - |
| - | - | - | 0.41 | 0.41 | 0.43 | 0.42 | 0.41 | 0.40 | 0.37 | - | - | - |
| - | - | - | - | 0.36 | 0.36 | 0.36 | 0.36 | 0.35 | - | - | - | - |
| - | - | - | - | - | - | - | - | - | - | - | - | - |



## #5) A Trunk Sewer Modelling Approach to Match the Measured Areal Distribution of Rain

The above ARF results can be approximated as a series of concentric circles centered on the maxima, which can also be represented in an X-Y format chart as shown below.



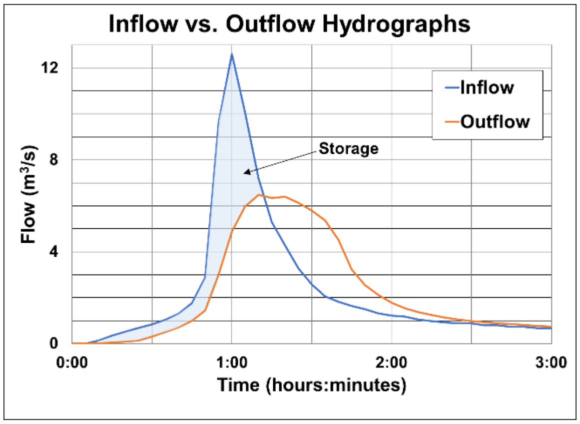
The following trunk system modelling approach for the 1:100 year event scenario was undertaken that closely represented the averaged areal distribution of the short duration weather radar flood events:

- the 1:100 year design event was applied over sub-catchment areas within a 3 km$^2$ circle of area centered on the project site;
- the 1:10 year event was applied over sub-catchment areas beyond the 3 km$^2$ circle out to a 20 km$^2$ concentric circle; and
- the 1:5 year event was applied beyond the 20 km$^2$ concentric circle.

The same approach can be used when assessing other design event conditions, with the storm values within the three areal zones adjusted to reflect the design event under analysis, as provided in this paper.

### #6) Refined Trunk Sewer Modelling Approach More Accurate and Leads to Cost Savings

Accounting for the areal distribution of rain and CB inlet capacities when modelling trunk sewer systems will lead to a much more realistic understanding of actual conveyance capacities available in the trunks during design events, which will lead to better, more knowledge-based decision making, much smaller storage requirements and much more cost-effective designs. For the YHT project, the 7,000 m$^3$ of storage (blue shaded area on figure), is estimated to cost \$74 million. Traditional trunk modelling that would require all inflows to be stored, would have cost much, much more.



## 6.0 Recommendations

### #1) Incorporate CB Inlet Controls in Models

Catch basin inlet controls should be incorporated into all computer simulation models of storm or combined sewer systems to better reflect runoff flows routing to sewer when analyzing design events larger than about a 1:2 year to 1:5 year event. Where practicable, undertake limited model calibration to an actual monitored large event as a means of estimating CB inlet capacities. Where not practicable to calibrate, consult with the local approval authority for any insights on potential CB inlet capacities within the trunk catchment area, or at a minimum, conservatively assume 1:5 year inlet capacity. An assumption of 1:5 year CB inlet capacity can be expected to provide results much closer to actual conditions during assessment of large events like the 1:100 year event, over the condition where no inlet restrictions are modelled.

## #2) Account for the Areal Distribution of Rain When Modelling Large Systems

When assessing the performance of storm or combined sewer systems with catchment areas larger than a few square kilometers (or a few hundred hectares), apply the areal distribution of rain methodology outlined in this paper towards better representing actual rainfall conditions that occur over large areas, and actual available capacities within the local trunk sewer system to accommodate during-event discharges from your project. The following plot is appropriate for use when assessing short duration large flood events in Edmonton. Utilize weather radar data, as described in this paper, to develop an approach suitable for your community.