Case Study

Evaluation of the Potential Impact of Rainfall Intensity Variation due to Climate Change on Existing Drainage Infrastructure

Thewodros G. Mamo, Ph.D., P.E., D.WRE, M.ASCE[1]

Abstract: The potential impact of climate change on the existing drainage infrastructure has been an essential aspect of many hydrological studies. Climate change that will increase the intensity of precipitation will also increase the magnitude of the design discharge and thus would probably result in adverse effects on the existing drainage facilities. This paper aims to evaluate the potential impact of rainfall intensity variation due to climate change on the existing drainage infrastructure by investigating whether (1) the stormwater drainage infrastructure designed for preclimate conditions is able to sustain future higher discharges, and (2) new design guidelines are necessary to be established to include the potential rainfall intensity variation due to climate change. A case study was conducted using 34 years of rainfall data (1980–2013) obtained from the National Climatic Data Center (NCDC). These data and the weather scenario data projected by the four run global circulation model (GCMs) under the three emissions scenarios coupled with stochastic weather generator model which generates daily weather time series statistically were used to update the current intensity-duration-frequency curve to reflect the rainfall intensity variation due to climate change. Furthermore, runoff simulation using a storm and sanitary software program was performed to analyze whether the increase in the intensity of rainfall due to climate change would have an adverse impact on the current drainage system to convey excess runoff. The results showed that most elements of the current drainage infrastructure in the boundary of the study area were inadequate to convey excess runoff. However, climate change magnifies the problems that already exist in an aging drainage infrastructure. Furthermore, considering the rehabilitation or replacement rates of these aging infrastructures are relatively slow, emphasis must not lie only on the future climate change, but also on identifying the weak spots in the system coupled with, the economic and environmental factors before any changes in design criteria can be recommended due to climate change. **DOI:** **10.1061/(ASCE)IR.1943-4774.0000887.**

Author keywords: Climate change; Adaptation; Rainfall intensity; Drainage infrastructure; Intensity-duration-frequency (IDF) curve.

Introduction

The intensification and dramatic changes in the hydrological cycle [e.g., more intense rainfall and extreme weather events such as Hurricane Irene in 2011 and Superstorm Sandy in 2012 in the United States and Typhoon Jose (Halong) in 2014, in the Philippines] can cause significant economic and environmental impacts by flooding vast urban areas, overflowing sewers, and damaging stormwater drainage infrastructure. Furthermore, heavy rainfall intensity during wet or rainy seasons is also projected to become more common while urbanization continues. Subsequently, one of the most vulnerable systems due to these adverse effects of heavy rainfall is most likely to include urban drainage infrastructure networks (Adger et al. 2007; Alzahrani 2013; Andreasson et al. 2004; Arisz and Burrell 2006; Ashley et al. 2005; Denault 2001). Even though the effects of climate change at the local level are not well understood and appear to be gradual, their potential cumulative impact over the service life cycle of drainage infrastructure warrants changes in the basic philosophy of the technical design of stormwater drainage infrastructure (Arisz and Burrell 2006; Guo 2006; Karl et al. 1988; Smite et al. 1999).

Adaptation to rainfall variation becomes one of the major responses to climate change. However, it was given little attention when climate change emerged as an important issue in the 1980s. Mitigation has always been synonymous with combating climate change. It is only in the last decade that adaptation has emerged as a credible response to climate change. Climate change is now accepted by most people as being a reality, and there is a strong probability that rainfall events are going to be more intense in the future (Adger et al. 2007; Denault 2001; Fowler et al. 1995; Molavi et al. 2013; Rossman et al. 1998; Scheraga et al. 1998; Willems 2000).

Drainage infrastructures are designed based on the capacity to pass design discharges, such as the 1-in-100-year flood or the probable maximum flood (PMF) in cases where the consequences of failure are extreme. Climate change that increases precipitation will also increase the magnitude of these design discharges and subsequently affect both minor and major drainage infrastructure systems designed to convey excess runoff when the capacity of the minor system is exceeded (Butler and Davies 2004; Endreny et al. 2009; Gordon et al. 1992; Grum et al. 2005; Koutsoyiannis et al. 1998). So is it necessary to establish new guidelines to include the potential rainfall intensity variations due to climate change?

[1]Dept. of Civil and Urban Engineering, New York Univ., Polytechnic School of Engineering, 6 Metro Tech Center, Brooklyn, NY 1120. E-mail: tmamo@nyu.edu

Note. This manuscript was submitted on October 22, 2014; approved on January 16, 2015; published online on March 6, 2015. Discussion period open until August 6, 2015; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Irrigation and Drainage Engineering***, © ASCE, ISSN 0733-9437/05015002(7)/$25.00.

Methodology

The rainfall intensity-duration-frequency (IDF) relationship is one of the most commonly used tools in water resources engineering, either for the planning, designing, and operating of water resource projects or the protection of various engineering projects against floods (Griffis and Stedinger 2007a; Guo 2006;

J. Irrig. Drain Eng., 2015, 141(10): 05015002

Koutsoyiannis et al. 1998; Okonkwo and Mbajiorgu 2010). Generally, the main characteristics of rainfall are intensity, duration, total amount, and frequency or recurrence interval. The rainfall IDF curve illustrates the relationship between mean precipitation intensity and frequency of occurrence (the inverse of the return period) for different time intervals of a given duration. These intervals over which precipitation intensity is averaged are called durations (Chow et al. 1998; Solaiman et al. 2011; Willems 2000). The intensity is the time rate of precipitation, which is expressed in depth per unit of time (in./h). The average intensity is commonly used and can be expressed as

$$i = \frac{P}{D} \tag{1}$$

where P = rainfall depth (mm or in.); and D = duration, usually given in hours. The frequency is usually expressed in terms of return period (T), which is the average length of time between precipitation events that equal or exceed the design magnitude.

The current IDF curve are based on the concept of temporal stationarity, which assume that, the occurrence probability of extreme rainfall intensity events is not expected to change over time. However, as climate has shown significant changes in rainfall characteristics in many regions, depending only on the current IDF curve concept or stationary climate change assumption may lead to underestimation of the extreme rainfall intensity events. Therefore, given the observed increase in heavy rainfall intensity events, the author argues that the IDF curve should be updated to account for future climate change. For this purpose, two climate change scenarios are used in the analysis: (1) historic climate change data for 34-years (1980–2013) obtained from the National Climatic Data Center (NCDC) was used to set up the relationship between the intensity, duration, total amount and frequency or recurrence interval; and (2) monthly mean precipitation Wet weather scenario data projected by the four run global circulation model (GCMs) under the three emissions scenarios were downloaded from the intergovernmental panel on climate change (IPCC) data distribution center (http://www.ipcc-data.org) for a period of 2020 and 2055. Furthermore, control simulations were investigated for the estimation of the suitability of different GCMs to describe climatic conditions, by comparing the modelled and observed monthly mean precipitation data during 1980–2013.

The simulation output data, and then used as the weather generator input using LARS-WG. LARS-WG is a stochastic weather generator model generating daily weather time series statistically similar to the observed weather (Wilks and Wilby 1999). WGs were adopted in climate change impact studies as a computationally inexpensive tool to generate scenarios with high temporal and spatial resolutions based on the output from a GCM (Barrow and Semenov 1995; Dubrovsky et al. 2005; Hansen 2002; Wilks 1992; Wilks and Wilby 1999). Furthermore, for this research goodness of fit tests based on chi-square statistic and empirical distribution function (EDF) [statistics Kolmogorov–Smirnov (KS) and Anderson darling (AD) test] are used for evaluating the suitability of different probability distributions.

The simulation output results and analysis show that: (1) in general the rainfall intensity duration and frequency will increase under climate change; (2) the wet climate scenario reveals increase in rainfall intensity; (3) the increase in rainfall intensity and magnitude will have significant implications the way current and future municipal drainage infrastructure is designed, operated, and maintained; and finally (4) it also raises the fundamental question for municipal engineers whether new design guidelines are necessary to be established and the current IDF curves should be revised and updated to reflect the potential impact of climate change. For this purpose runoff simulation using *SWMM version 5* (http://www2.epa.gov/water-research/storm-water-management-model-swmm) storm and sanitary software also performed to analyze whether the increase in the intensity of rainfall due to climate change would have an adverse impact on the current drainage system to convey the excess runoff. Should new design guidelines are necessary to be established.

Research Project Area

The location looked at in this study is Astoria Heights (also called Upper Ditmars), a district of the borough of Queens in New York City. The total area is approximately 8.2 ha. Figs. 1 and 2 show the general location and drainage map of the study area.

Data Collection and Analysis

The maximum annual precipitations with different durations of rainfall data for a period of 34 years (1980–2013) obtained from LaGuardia Airport station were used as the main data set since the study area was very close to the local weather extreme and record station of the National Oceanic and Atmospheric Administration (NOAA) department of the NCDC. Given this information, the data were also subjected to statistical procedures that included calculating the mean, maximum, minimum, frequency, standard deviation, and other measurements. Furthermore, descriptive and graphical statistical analysis was also run for different durations of rainfall intensity in order to examine whether the data were random. The time series plot of the maximum precipitation is shown in Fig. 3. Comparatively, there is no pattern in this plot; as a result, the author concludes that the data were a random sample. A descriptive statistical analysis for 24-h precipitation is shown in Table 1.

The mean and the standard deviation are $\bar{X}(3.2)$, and $\delta(1.11)$, respectively. Similarly, by repeating the same statistical procedure for all different durations, the mean and standard deviation of the maximum annual precipitation were found (Table 2).

Graphical analysis was also done using the *MATLAB* fitting tool graphical interface. Three different types of probability distribution functions (normal, lognormal, and Weibull) were fitted to the data. Figs. 4–6 show the fitted probability density functions, probability cumulative functions, and probability plots, respectively. Comparing the three different fitted functions, it can be concluded that the normal and Weibull distributions fit the data with smaller error than the lognormal distribution. As a result, the author chose to use the normal distribution function since forecasting the cumulative probability of the maximum annual rainfall result using the Normal and Weibull distributions are very close.

In the final analysis, after the probability distribution function of the maximum rainfall for different durations (D) determined, the maximum intensity of the rainfall also was forecasted using Eq. (7).

Updating Existing IDF Curve Approaches

The first step to construct the IDF curve for a given region is to assess the local rainfall data to determine the maximum rainfall depth associated with each year, and at least 25 years of rainfall intensity data should be considered (Gordon et al. 1992; Solaiman et al. 2011; Willems 2000). Consequently, the maximum rainfall depth should be determined for the different durations of rainfall during these 25 years, and a descriptive statistical analysis must be done for each duration to determine the mean and standard

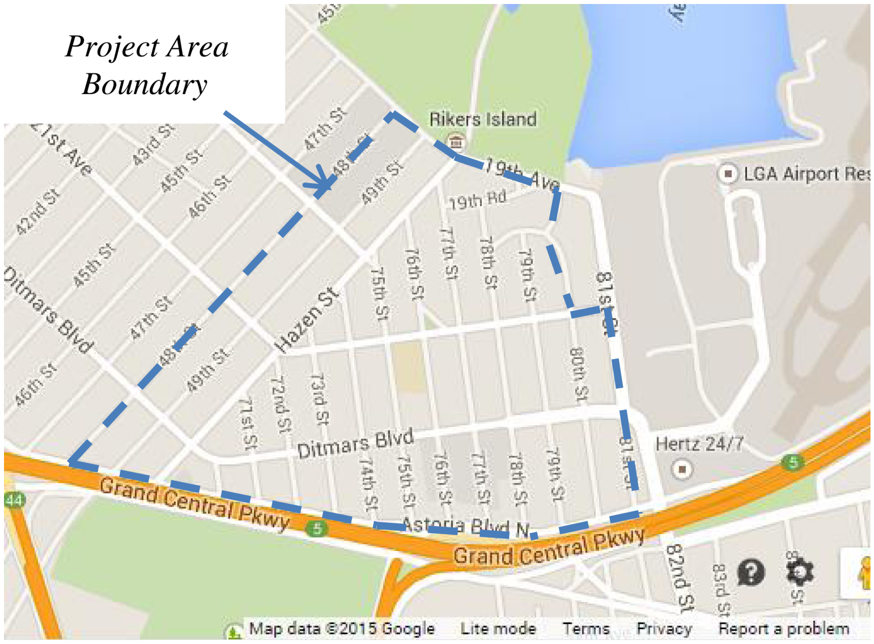

Fig. 1. General location of study area (map data © Google)

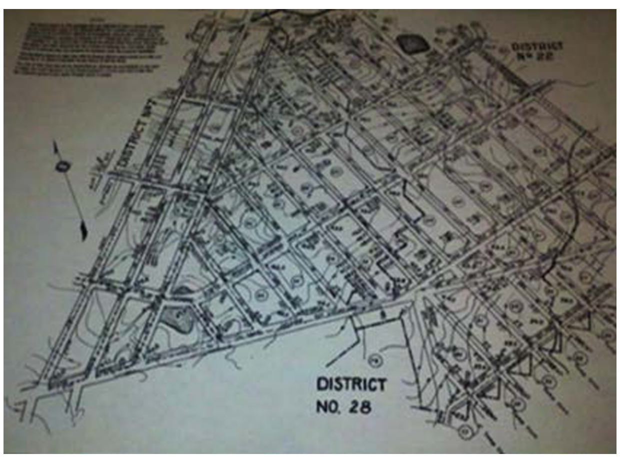

Fig. 2. Drainage plan of study area (image by author)

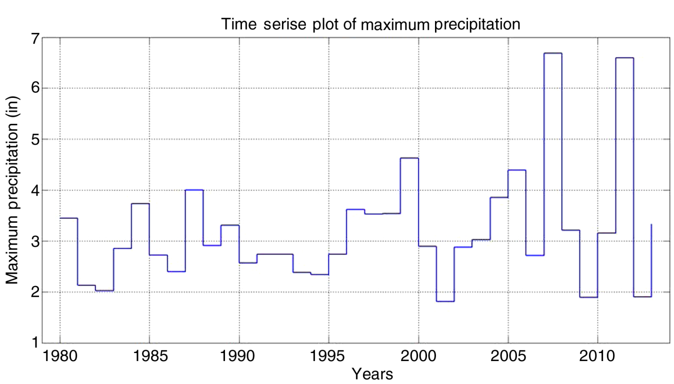

Fig. 3. Time series plot of the maximum precipitation from 1980 to 2013

Table 1. Descriptive Statistical Analysis for 24-h Precipitation

Descriptive statistics for the 24-h duration	
Main feature	Value
Mean	3.20
Standard error	0.19
Median	2.9
Mode	2.74
Standard deviation	1.11
Sample variance	1.24
Kurtosis	3.91
Skewness	1.76
Range	4.88
Minimum	1.81
Maximum	6.69
Sum	108.67
Count	34

Table 2. Mean and Standard Deviation of the Sampled Maximum Precipitation in Different Durations of Rainfall from 1980 to 2013

Duration (h)	Mean [mm (in.)]	Standard deviation
1	46.99 (1.85)	0.42
2	53.85 (2.12)	0.47
3	59.18 (2.33)	0.56
6	67.56 (2.66)	0.67
12	76.20 (3.00)	0.92
24	81.28 (3.20)	1.11
48	82.80 (3.26)	1.11
72	87.63 (3.45)	0.92
120	98.30 (3.87)	0.96
168	131.57 (5.18)	1.1

deviation as functions of duration. As a result, the model will have two arrays: one for the mean depth of rainfall $\bar{X}(D)$, which is a function of duration of the rainfall; and another for the standard deviation of the depth of rainfall $\delta(D)$.

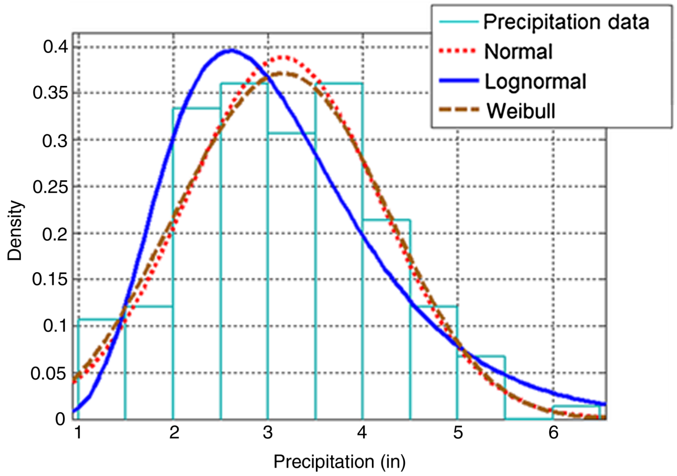

Fig. 4. Histogram of the maximum precipitation for the 24-h duration and the fitted probability density function (1980–2013)

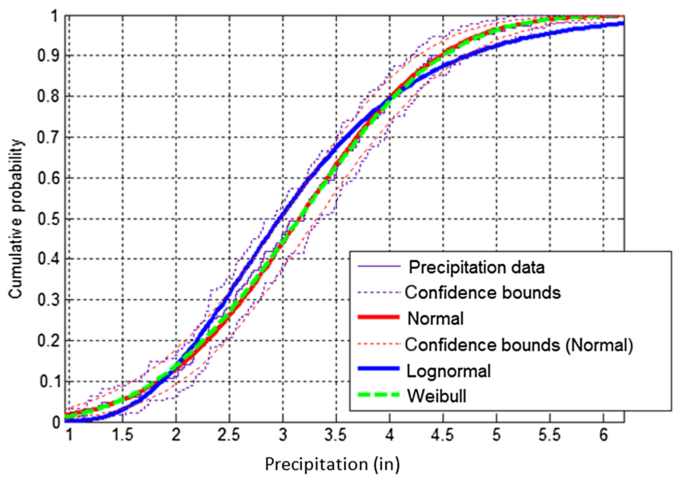

Fig. 5. Fitted probability cumulative functions for the maximum precipitation for a 24-h duration

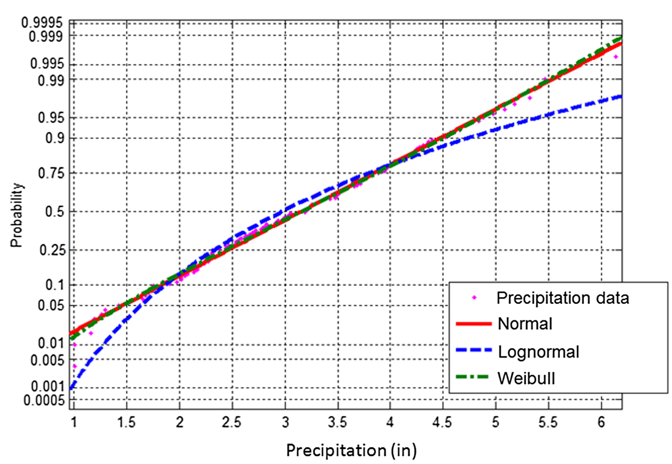

Fig. 6. Probability plots for the maximum precipitation for a 24-h duration

The second step is to fit a probability distribution function (PDF) or a cumulative distribution function (CDF) to each group comprised of the data values for a specific duration. It is possible to relate the maximum rainfall intensity for each time interval with the corresponding return period from the cumulative distribution function. Given a return period T, its corresponding cumulative frequency F will be

$$F = 1 - \frac{1}{T} \quad \text{or} \quad T = \frac{1}{1-F} \tag{2}$$

Once a cumulative frequency is known, the maximum rainfall intensity is determined using the chosen theoretical distribution function such as normal, Weibull, and lognormal (Griffis and Stedinger 2007b; Mailhot et al. 2007; Mirhosseini et al. 2014; Solaiman et al. 2011). The objective of frequency analysis is to relate the magnitude of events to their frequency of occurrence through probability distribution. It is assumed the events (i.e., data) are independent and come from identical distribution. Once a distribution function has been selected and its parameters estimated in this case the normal distribution function (Fig. 7) is selected since forecasting the cumulative probability of the maximum annual rainfall result using the normal and Weibull are very close, as described previously

$$x_T = \bar{x} + K_T\delta \qquad \text{Using } x_T = \bar{x} + K_T\delta \text{ proposed by Chow} \tag{3}$$

where x_T = return period; K_T = return period; T = return period; $\bar{x}$ = sample mean; and δ = sample standard deviation.

The magnitude of the hydrologic event of the T-year event can be represented as follows:

$$X_T = \mu + K_T\delta \tag{4}$$

where X_T represents the magnitude of T-year, μ and σ are the mean and standard deviation of the annual maximum series, and is a frequency factor depending on the return period, T. The frequency factor is obtained using the relationship

$$K_T = \frac{X_T - \mu}{\delta} \tag{5}$$

This is the same as the standard normal variable Z, and using the cumulative distribution function for the standard normal distribution for any given T-year return period

$$K_T = Z_F = Z_{1-(1/T)} \tag{6}$$

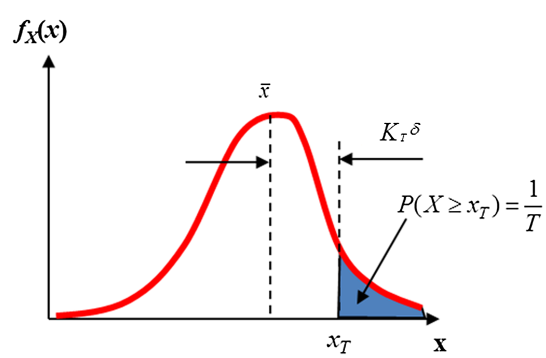

Fig. 7. Magnitude of an extreme event X_T expressed as a deviation of $K_T\delta$ from the mean μ, where K_T is the frequency factor

In the third step, the rainfall intensities for each duration and a data set from a selected return period, such as 2, 5, or 10 years, are calculated using Eqs. (3) and (5) as follows:

$$i_T(D) = \frac{X_T(D)}{D} = \frac{1}{D}[\bar{X}(D) + Z_{1-(1/T)}\delta(D)] \tag{7}$$

where $\bar{X}(D)$ and $i_T(D)$ are, respectively, the calculated or forecasted rainfall depth and the maximum rainfall intensity associated with the duration D for the return period T years.

The return period for a given duration and maximum intensity (T) is the average time interval between exceedances of the value (D). It is well known that for the annual series, under the assumption that consecutive values are independent, the return period of an event is the reciprocal of the probability of exceedance of that event, i.e. (Butler and Davies 2004)

$$T = \frac{1}{1-F} \tag{8}$$

Demonstration

For demonstration purposes, to calculate the maximum intensity of the rainfall with a 10-year return period and 24-h duration and using Eq. (7) and

$$i_T(D) = \frac{X_T(D)}{D} = \frac{1}{D}[\bar{X}(D) + Z_{1-(1/T)}\delta(D)] \Rightarrow i_{10(24)} = \frac{x_{10}(24)}{24}$$

where $D = 24$ and $T = 10$, and from the data in Table 2, the mean $\bar{X}(3.2)$ and standard deviation $\delta(1.11)$ are

$$= \frac{1}{24}[\bar{X}(24) + Z_{1-(1/T)}\delta(24)]$$
$$= \frac{1}{24}[(3.2) + Z_{1-(1/T)}(1.11)] \Rightarrow 4.93 \text{ mm/h}$$

For the purpose of constructing the IDF curve, similar calculations were performed for 1, 2, 3, 6, 12, 24, 48, 72, 120, and 168 h and 2-, 5-, 10-, 25-, 50-, and 100-year return periods, and the results are shown in Table 3.

Runoff Simulation and Modeling Result Analysis

A runoff simulation using *SWMM-5* storm and sanitary software was performed to analyze whether the increase in the intensity of rainfall due to climate change would have an adverse impact on the current drainage system to convey excess runoff. The model result shows a 23.4% increase on the peak stormwater runoff due to an increase in intensity from 44.45 mm/h (1.75 in./h) to 54.61 mm/h (2.15 in./h) when it compared with the current standard design criterion in New York City intensity-duration values for a 5-year return period to the updated IDF curve (Figs. 8 and 9) for the same duration of return period, which is 18.6% increase of rainfall intensity. As a result, most elements of the current drainage infrastructure in the boundary of the study area were inadequate to convey the excess runoff generated using the updated IDF curve. However, the current state of stormwater infrastructure in the study area in terms of capacity, type and age of pipes, sediment deposition, and drainage system configuration (combined sewer system), as well as the maintenance history, including a long-term trend that causes deterioration of the existing infrastructure through benign neglect, and population growth, also has an impact of similar or greater magnitude than climate change on the model results. Furthermore, the study area drainage systems were constructed in 1928

Table 3. Estimated Value for the Maximum Rainfall Intensity As a Function of Duration and Return Period

N-year	Duration (h)									
event	1-h	2-h	3-h	6-h	12-h	24-h	48-h	72-h	120-h	168-h
	Maximum rainfall intensity [mm/h (in./h)]									
2	45.237 (1.781)	25.933 (1.021)	18.948 (0.746)	10.795 (0.425)	6.020 (0.237)	3.200 (0.126)	1.626 (0.064)	1.168 (0.046)	0.787 (0.031)	0.762 (0.030)
5	54.661 (2.152)	31.217 (1.229)	23.139 (0.911)	13.310 (0.524)	7.747 (0.305)	4.242 (0.167)	2.159 (0.085)	1.448 (0.057)	0.965 (0.038)	0.914 (0.036)
10	60.909 (2.398)	34.722 (1.367)	25.908 (1.020)	14.961 (0.589)	8.890 (0.350)	4.928 (0.194)	2.489 (0.098)	1.651 (0.065)	1.092 (0.043)	0.991 (0.039)
25	68.783 (2.708)	39.116 (1.540)	29.413 (1.158)	17.069 (0.672)	10.338 (0.407)	4.928 (0.194)	2.946 (0.116)	1.880 (0.074)	1.245 (0.049)	1.118 (0.044)
50	74.651 (2.939)	42.393 (1.669)	32.029 (1.261)	18.618 (0.733)	11.405 (0.449)	6.426 (0.253)	3.251 (0.128)	2.057 (0.081)	1.219 (0.048)	1.219 (0.048)
100	80.467 (3.168)	45.644 (1.797)	34.595 (1.362)	20.168 (0.794)	12.471 (0.491)	7.061 (0.278)	3.581 (0.141)	2.235 (0.088)	1.448 (0.057)	1.295 (0.051)

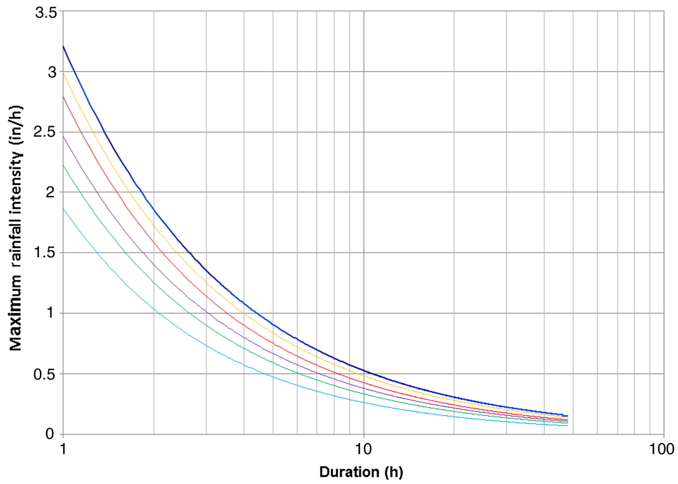

Fig. 8. Plot of the linear and duration logarithmic IDF curve for the duration of 1–48 h for 2- and 100-year events

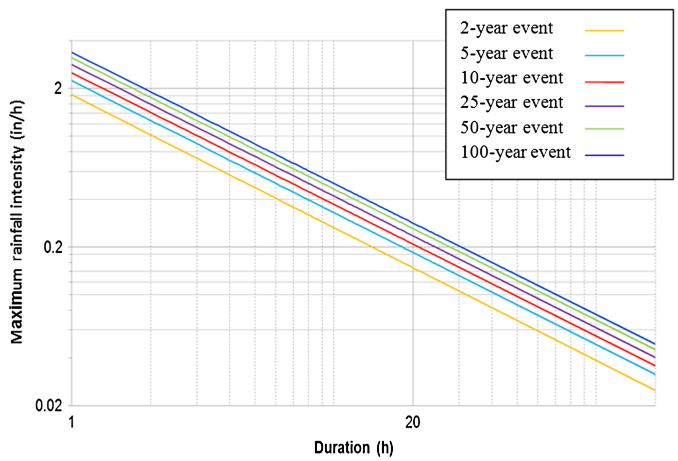

Fig. 9. Plot of the linear and duration logarithmic IDF curve for the duration of 1–168 h for 2- and 100-year events

for areas whose impervious surfaces were fewer and smaller than those today, which will greatly affect the urban runoff results.

Other factors, such as the high precipitation values during Hurricane Irene in 2011 and Superstorm Sandy in 2012, also affect the model results during upgrading of the IDF curve for this particular research project since the rainfall intensity was the highest.

Conclusions

The results of this research showed that most elements of the current drainage infrastructure in the boundary of the study area were inadequate to convey excess runoff. However, climate change magnifies the problems that already exist in an aging drainage infrastructure. Furthermore, the rehabilitation or replacement rates of these aging infrastructures are relatively slow. As a result, emphasis must be placed not only on the future climate change, but also on identifying the weak spots in the system, coupled with the economic and environmental factors, before any changes in design criteria can be recommended due to climate change. This finding, however, is characteristic of this case study area and may not apply to other watersheds.

References

Adger, W. N., et al. (2007). "Assessment of adaptation practices, options, constraints, and capacity." *Contribution of Working Group II to the Fourth Assessment Rep. of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, U.K., 719–743.

Alzahrani, F. (2013). "An approach to quantifying uncertainty in estimates of intensity duration frequency (IDF) curves." Univ. of Waterloo, Waterloo, ON, Canada.

Andréasson, J., Bergström, S., Carlsson, B., Graham, L. P., and Lindström, G. (2004). "Hydrological change-climate change impact simulations for Sweden." *J. Human Environ.*, 33(4), 228–234.

Arisz, H., and Burrell, B. C. (2006). "Urban drainage infrastructure planning and design considering climate change." *Proc., Conf., EIC Climate Change Technology, 2006 IEEE*, IEEE, Ottawa, 1–9.

Ashley, R. M., Balmforth, D. J., Saul, A. J., and Blanksby, J. D. (2005). "Flooding in the future predicting climate change, risks, and responses in urban areas." *Water Sci. Technol.*, 55(5), 265–273.

Barrow, E. M., and Semenov, M. A. (1995). "Climate change scenarios with high spatial and temporal resolution for agricultural applications." *Forestry*, 68(4), 349–360.

Butler, D., and Davies, J. (2004). *Urban drainage*, CRC Press, Taylor & Francis, New York.

Chow, V., Maidment, R. D., and Mays, L. W. (1998). *Applied hydrology*, McGraw-Hill, New York.

Denault, C. (2001). "Assessment of the likely impact of climate change on infrastructure and natural ecosystems of a small watershed in British Columbia: Implications for hydraulic infrastructure design and stormwater management." M.A.Sc. thesis, Univ. of British Columbia, Vancouver, BC, Canada, 84.

Dubrovsky, M., Nemesova, I., and Kalvova, J. (2005). "Uncertainties in climate change scenarios for the Czech Republic." *Clim. Res.*, 29(2), 139–156.

Endreny, T. A., and Imbeah, N. (2009). "Generating robust rainfall intensity–duration–frequency estimates with short-record satellite data." *J. Hydrol.*, 371(1), 182–191.

Fowler, A. M., and Hennessy, K. J. (1995). "Potential impacts of global warming on the frequency and magnitude of heavy precipitation." *Natural Hazards*, 11(3), 283–303.

Gordon, H. B., Whetton, P. H., Pittock, A. B., Fowler, A. M., and Haylock, M. R. (1992). "Simulated changes in daily rainfall intensity due to the enhanced greenhouse effect: Implications for extreme rainfall events." *Clim. Dyn.*, 8(2), 83–102.

Griffis, V. W., and Stedinger, J. (2007a). "Log-Pearson Type 3 distribution and its application in flood frequency analysis. II: Parameter estimation methods." *J. Hydrol. Eng.*, 10.1061/(ASCE)1084-0699(2007)12:5(492), 492–500.

Griffis, V. W., and Stedinger, J. R. (2007b). "Log-Pearson Type 3 distribution and its application in flood frequency analysis. "I: Distribution characteristics." *J. Hydrol. Eng.*, 10.1061/(ASCE)1084-0699(2007)12:5(482), 482–491.

Grum, M., Jørgensen, A. T., Johansen, R. M., and Linde, J. J. (2005). "The effect of climate change on urban drainage: An evaluation based on regional climate model simulations." *Proc., 10th Int. Conf. on Urban Drainage*, Institute of Environment and Resources Technical Univ. of Denmark, Copenhagen, Denmark, 21–26.

Guo, Y. (2006). "Updating rainfall IDF relationships to maintain urban drainage design standards." *J. Hydrol. Eng.*, 10.1061/(ASCE)1084-0699(2006)11:5(506), 506–509.

Hansen, J. W. (2002). "Realizing the potential benefits of climate prediction to agriculture: Issues, approaches, challenges." *Agric. syst.*, 74(3), 309–330.

Karl, T. R., Diaz, H. F., and Kukla, G. (1988). "Urbanization: its detection and effects in the United States climate record." *J. Climate*, 1(11), 1099–1123.

Koutsoyiannis, D., Kozonis, D., and Manetas, A. (1998). "A mathematical framework for studying rainfall intensity-duration-frequency relationships." *J. Hydrol.*, 206(1–2), 118–135.

Mailhot, A., Duchesne, S., Caya, D., and Talbot, G. (2007). "Assessment of future change in intensity-duration-frequency (IDF) curves for

southern Quebec using the Canadian regional climate model (CRCM)." *J. Hydrol.*, 347(1), 197–210.
Mirhosseini, G., Srivastava, P., and Fang, X. (2014). "Developing rainfall intensity-duration-frequency curves for Alabama under future climate scenarios using artificial neural networks." *J. Hydrol. Eng.*, 10.1061/(ASCE)HE.1943-5584.0000962, 04014022.
Molavi, S., Tran, H. D., and Muttil, N. (2013). "Implementing future climate change scenarios using stormwater drainage model for an urban catchment in Melbourne." *Proc., 20th Conf. of the Int. Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, 2506–2512.
Okonkwo, G. I., Mbajiorgu, C. C. (2010). "Rainfall intensity-duration-frequency analysis for southeastern Nigeria." *Agric. Eng. Int. CIGR J.*, 12(1), 22–30.
Rossman, L. A., et al. (1998). "Risks, opportunities and adaptation to climate change." *Clim. Res.*, 11(1), 85–95.
Scheraga, J. D., and Grambsch, A. E. (1998). "Risks, opportunities, and adaptation to climate change." *Clim. Res.*, 11(1), 85–95.
Smite, B., Burton, I., Klein, R. J., and Street, R. (1999). "The science of adaptation: A framework for assessment." *Mitigation and Adaptation Strategies for Global Change*, 4(3–4), 199–213.
Solaiman, T. A., and Simonovic, S. P. (2011). "Development of probability based intensity-duration-frequency curves under climate change." *Water Resources Research Rep. Book 34*, Dept. of Civil and Environmental Engineering, Univ. of Western Ontario, London, ON, Canada.
Wilks, D. S. (1992). "Adapting stochastic weather generation algorithms for climate changes studies." *Climate Change*, 22(1), 67–84.
Wilks, D. S., and Wilby, R. L. (1999). "The weather generation game: A review of stochastic weather models." *Prog. Phys. Geogr.*, 23(3), 329–357.
Willems, P. (2000). "Compound intensity-duration-frequency-relationships of extreme precipitation for two seasons and two storm types." *J. Hydrol.*, 233(1–4), 189–205.