Date: February 5, 2018
To: John Mathews, Ohio EPA
From: Justin Reinhart, Ohio EPA
Jay Dorsey, Ohio State University Stormwater Management Program
Re: Intensity-Duration Curve for Water Quality Flow

Background

Traditional stormwater practices utilize the extended detention of a specified runoff volume for a specified length of time to achieve the desired water quality treatment. The NPDES general permit for construction activities (CGP) requires a detention volume known as the "water quality volume" or WQv to be captured and released over a 24 to 48-hour duration. The WQv in the proposed CGP update is the runoff from a 0.9-inch precipitation depth. This runoff depth, combined with estimated total suspended solids (TSS) removal efficiencies of 90% for extended detention and infiltration best management practices (BMPs) accepted for general use (Table 5), results in removal of 80% of average annual TSS.

A number of newer stormwater treatment practices, including most proprietary manufactured treatment devices, utilize processes such as filtering or centrifugal separation instead of extended detention to remove sediment. The proposed CGP considers these "flow-through" practices as alternatives available when Table 5 practices are not feasible and on sites with a negligible impact on stream stability, thereby not requiring extended detention. TSS removal efficiencies for a proposed alternative BMP must be verified through laboratory or field testing consistent with the certification programs developed by the state of New Jersey or the state of Washington. For an alternative BMP to be acceptable, test results must demonstrate that the minimum TSS removal rate is 80% at the design flow rate, or 50% TSS removal if proposed as pre-treatment for non-infiltrating underground detention structures.

The design flow rate represents a "water quality treatment flow" or WQf. Similar to the WQv, the WQf will be used to appropriately size the water quality practice for the proposed land use, drainage area and time of concentration.

WEF's Manual of Practice *Design of Urban Stormwater Controls* (WEF/ASCE, 2012) outlines three methods to establish a water quality treatment flow rate:

1. Transform the WQv into a flow rate using the Santa Barbara Unit Hydrograph (SBUH) model;
2. Develop a hydrograph of the design event or water quality event and utilize the SCS Curve Number (CN) methodology to determine a peak discharge; or
3. Utilize the Rational Method to estimate peak discharge and an Intensity-Duration-Frequency (IDF) curve generated for the WQv event from the shape of other local IDF curves.

The SBUH model, developed in the 1970's as an alternative to the rational method, does not appear to be widely used beyond the west coast. Because of the challenges associated with implementing a hydrologic model that local designers are not familiar with, this method was not considered.

NRCS curve number (CN) methodology is generally known to underestimate stormwater runoff from smaller events such as the water quality event (Claytor and Schueler, 1996; Pitt, 1999). To overcome this, some states including New Jersey, Massachusetts, Connecticut, Virginia and Maryland have adopted a modified version of the CN method to convert the local WQv into a peak discharge rate.

The rational formula for estimating peak runoff is a widely used method for hydrologic and hydraulic design on small urban watersheds (Viessman et al, 1996). Developed in the 1890s, the rational method utilizes a simple relationship to predict peak discharge rate (Q) based on drainage area (A), a runoff coefficient (C) that is a function of land use and imperviousness, and rainfall intensity (i):

$$Q = CiA$$

Tabular values of the rational runoff coefficient C for various land uses are widely published and commonly accepted. Rainfall intensity (i) is the local average intensity lasting a duration equal to or longer than the time of concentration (tc) of the drainage area (Cleveland, 2011). To utilize the rational method for determining compliance with Ohio's post-construction water quality requirements, a water quality rainfall intensity appropriate for the proposed development site conditions (based on water quality event depth and tc) must be applied.

The use of an intensity-duration-frequency (IDF) curve allows the designer to adjust the water quality event intensity based on a site-specific tc. WEF/ASCE (2012) provides a procedure for developing an intensity-duration-frequency (IDF) curve for the WQv event using simple scaling from IDF curves available for higher recurrence intervals. Locally, the City of Columbus (2012) used the approach described by WEF/ASCE (2012) to develop an IDF curve for a 0.75-inch water quality precipitation event whereas the Ohio Department of Transportation (ODOT, 2017) instructs designers to utilize the rational formula with a single water quality flow rainfall intensity (0.65 in/hr) for all site conditions.

Given concerns regarding use of the CN method, we conclude the best way to develop a Water Quality Flow for the water quality design storm is through a simple scaled IDF curve and utilizing the rational method for estimating peak discharge.

Objectives

1) Develop a procedure for determining the "water quality flow" or WQf that results in average annual runoff treatment (i.e., treatment of 90% of average annual runoff) comparable to the water quality volume.

2) Provide methodology and, where appropriate, input data to calculate the WQf to be used in sizing or designing alternative BMPs for inclusion in the CGP.

Approach

To utilize the Rational Method to calculate a design water quality flow (WQf), a rainfall intensity is needed for the water quality treatment event.

The ideal approach to identifying the WQf that results in treatment of 90% of average annual runoff by a proposed BMP would be through a series of continuous runoff simulations using long-term rainfall data. From these simulations, the rainfall intensity value that results in 90% treatment of average annual volume could be backed out as a function of tc. Due to times of concentration typically in the 5-minute to 30-minute range, characterization of rainfall intensity for typical urban development drainage areas would require simulation using rainfall data with time-steps much shorter than an hour. Excellent quality hourly precipitation data is available for a number of weather stations in Ohio, but the historic precipitation data sets with recording time steps less than one hour (NWS ASOS program data at 1 and 5-minutes reporting interval, USCRN 5-minute data, and NWS cooperator station 15-minute data) all have so many missing data and data quality issues that the continuous simulation approach was rejected.

Therefore, a procedure based on the WEF/ASCE (2012) guidance was used to develop an intensity-duration-frequency (IDF) curve for the WQv event as follows:

- To follow the WEF/ASCE approach, an assumption had to be made about the duration of a representative WQv event. After evaluation of several possible durations for the 0.9-inch WQv event, six (6) hours was selected.
- Rainfall intensity values reported in NOAA Atlas 14 precipitation data (NWS-PFDS) with a 2-year recurrence interval were identified for time durations of 5, 10, 15, 30, 60, 120, 180, and 360-minutes. Values were averaged over the nine NWS weather stations used for Ohio precipitation analysis to create a statewide 2-year IDF.
- An IDF scaling factor was established by dividing the 0.9-inch, 6-hour rainfall average intensity (water quality event) by the statewide average 2-year, 6-hour rainfall intensity.
- The IDF scaling factor was used to derive 5, 10, 15, 30, 60, 120 and 180-minute water quality event IDF values from the 2-year values.
- A IDF curve through the eight (8) data points representing the water quality event was generated using interpolation and curve-smoothing.

Results/Discussion

A procedure based on the WEF/ASCE (2012) guidance was used to develop an intensity-duration-frequency (IDF) curve for the WQv event. In their widely cited *Rainfall Atlas of the Midwest*, Huff and Angel (1992) used a similar scaling approach to establish event depths of various durations for recurrence intervals less than one year. This approach previously was used in Ohio for development of the IDF curve used by the City of Columbus for the 0.75-inch WQv event (John Aldrich, personal communication).

Due to the lack of a direct relationship between peak discharge and runoff volume (Wenzel, 1982), an assumption had to be made about the duration of the proposed 0.9-inch WQv event. WEF/ASCE (2012) recommends using a water quality event duration of 1 to 2 hours. The New Jersey DEP (2004) used a 2-hour duration for their 1.25-inch stormwater quality design storm.

Following the assumption that moderate rainfalls occurring more often than once per year account for most of the runoff volume and pollutant load (Pitt, 1999), the 0.90-inch depth with durations of 1, 2, 3 and 6 hours having recurrence intervals of 8 months, 4 months, 3 months, and 2 months respectively (Huff and Angel, 1992) were evaluated. The 6-hour duration, with an approximate recurrence interval of 2 months, was selected as a reasonable representation of the water quality event. This selection was not a reflection of the anticipated recurrence interval or actual expected event duration, but a fit of the IDF based on professional judgement.

To develop an IDF for the 0.9-inch, 2-hour water quality event, IDF points for statewide rainfall average intensities with a recurrence interval of 2 years were identified for time durations of 5, 10, 15, 30, 60, 120, 180 and 360-minutes as shown in Table 1.

TABLE 1

Duration (Minutes):	**5**	**10**	**15**	**30**	**60**	**120**	**180**	**360**
Station Location	**2-year average intensity (in/hr)**							
Akron-Canton Airport	4.61	3.60	2.94	1.96	1.21	0.70	0.49	0.30
Cincinnati (Hebron, KY) Airport	5.46	4.26	3.47	2.32	1.43	0.83	0.59	0.36
Cleveland Airport	4.63	3.61	2.94	1.97	1.21	0.70	0.49	0.29
Columbus Airport	5.05	3.94	3.21	2.15	1.32	0.77	0.54	0.32
Dayton (Vandalia) Airport	5.11	3.99	3.25	2.18	1.34	0.78	0.55	0.33
Huntington (WV) Airport	5.09	3.97	3.24	2.17	1.33	0.76	0.53	0.31
Mansfield Airport	5.06	3.95	3.22	2.16	1.32	0.76	0.54	0.32
Toledo Airport	4.67	3.65	2.97	1.99	1.22	0.70	0.49	0.28
Youngstown Airport	4.50	3.52	2.87	1.92	1.18	0.68	0.48	0.29
Statewide Average 2-year	4.91	3.83	3.12	2.09	1.28	0.74	0.52	0.31
* NOAA Atlas14, Vol. 2, Ver. 3. Point Precipitation Frequency Estimates. Bonnin, G.M. et. al. accessed on-line 12/6/2017								

The position of the water quality IDF was established by placing the average hourly intensity for the 0.9-inch WQv event of:

$$\frac{0.9\ \text{inches}}{6\ \text{hours}} = 0.15\ \text{in/hr}$$

at the 6-hour (360 minute) duration. To develop the remaining points of the water quality IDF, a scale factor of 0.482 was developed by dividing the 360-minute intensity of 0.15 in/hr by the statewide average 2-year, 6-hour intensity of 0.31 in/hr. This scale factor was applied to the 5, 10, 15, 30, 60, 120 and 180-minute intensities to establish a water quality event rainfall intensity for those durations as shown in Table 2.

TABLE 2

Duration (Minutes):	5	10	15	30	60	120	180	360
	average intensity (in/hr)							
Statewide Average 2-yr	4.91	3.83	3.12	2.09	1.28	0.74	0.52	0.31
Water Quality Event	2.37	1.85	1.51	1.01	0.62	0.36	0.25	0.15

To develop a complete IDF curve that would allow a designer to select the rainfall intensity (i) value for a duration matching tc to the nearest minute, a curve was drawn through the 8 known points using interpolation and curve-smoothing.

The proposed IDF compares favorably to a simple scaling method proposed by Froehlich (2010). Table 3 shows the resulting difference between the proposed IDF and an IDF using simple scaling ratios in Froehlich (2010) [both scaled from the 2-year IDF].

TABLE 3

DURATION (minutes)	Proposed Intensity (in/hr)	Froehlich Ratio Intensity (in/hr)	% Difference
5	2.37	2.37	0.16
10	1.85	1.85	0.15
15	1.51	1.51	0.18
30	1.01	1.01	0.12

Conclusions/Recommendation

Ideally, the rainfall intensities used to calculate WQf would have been determined through continuous runoff simulations using historic rainfall data that resulted in determination of rainfall intensity values that resulted in 90% treatment of average annual runoff. Poor precipitation data quality for recording intervals shorter than one hour precluded this option.

It was determined that having rainfall intensities that reflect the typically short tc of developed watersheds necessitated an IDF curve for the water quality event. After reviewing the alternatives, the IDF scaling procedure outlined by WEF/ASCE (2012) seemed the most straightforward and defensible. As explained in WEF/ASCE (2012), the peak WQf can be estimated through “the rational equation, the time of concentration for the catchment, its runoff coefficient, and the IDF curve for the WQv”.

Therefore, the CGP should include:

1. Direction to use the rational equation in its standard form:

$$WQf = C * i * A$$

Where,
WQf = Water quality flow rate in cubic feet per second (cfs)
C = Rational method coefficient of runoff
i = Intensity (in/hr)
A = Area draining to the BMP (acres)

2. Instruction to use a duration equal to the calculated tc. Several documented equations could be used to estimate the tc for a drainage area given various parameters including slope, roughness coefficient, flow regime, and flow length. Because of the significance tc has on the peak discharge calculation under the rational method, guidance on estimated tc should be provided to designers within the *Rainwater and Land Development Manual*.

3. The WQf IDF curve (attachment 1). Presenting the curve as a table (attachment 2) in the CGP document will reduce errant readings from the chart and avoid reproduction challenges. A lower limit of 5 minutes and maximum of 60 minutes is recommended given the typical times of concentration of development sites.

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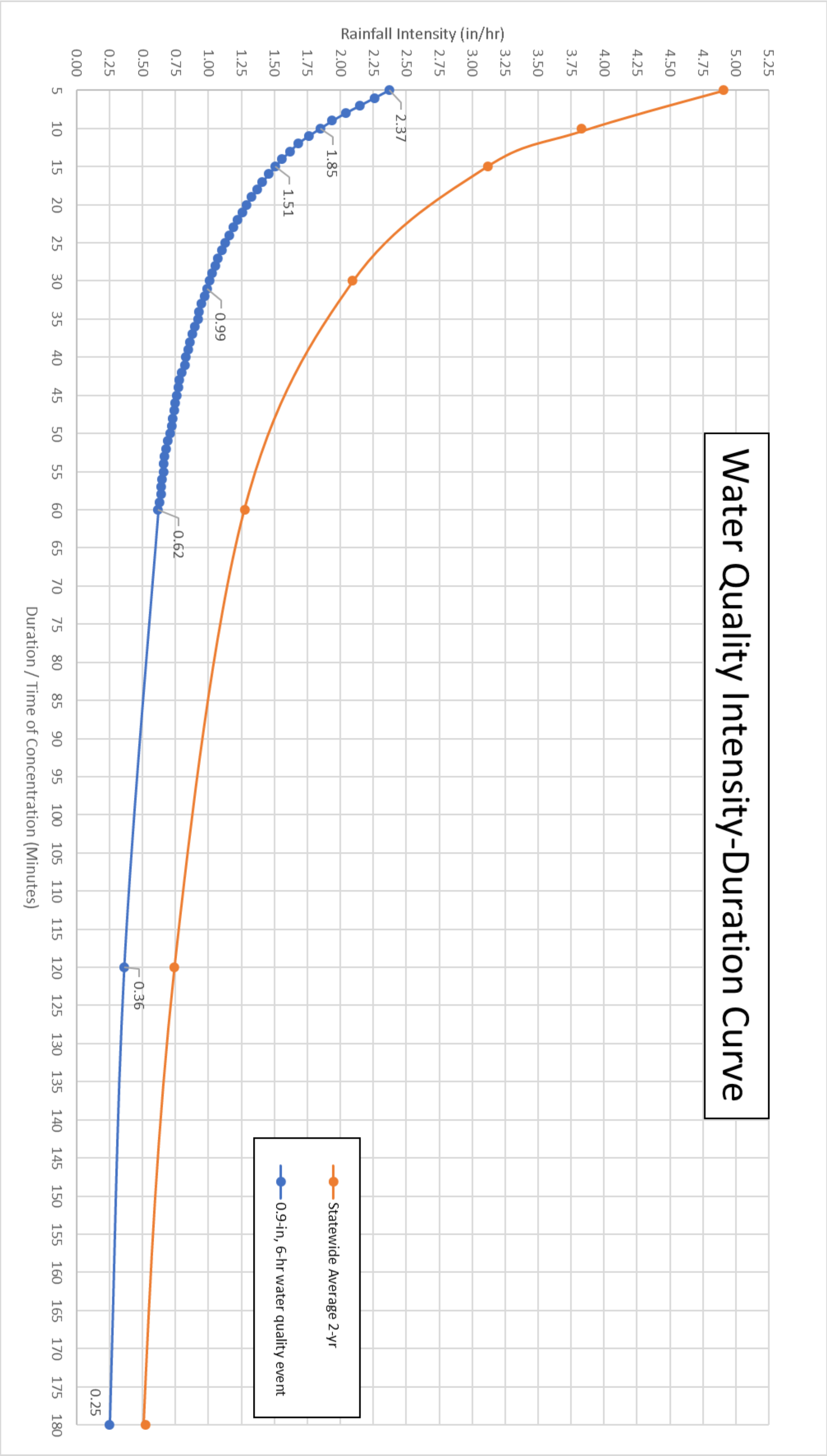
ATTACHMENT 1

Water Quality IDF Curve Plot



ATTACHMENT 2

Water Quality IDF Table

Duration (Minutes)	Water Quality Intensity (in/hr)	Duration (Minutes)	Water Quality Intensity (in/hr)
5	2.37	33	0.95
6	2.26	34	0.93
7	2.15	35	0.92
8	2.04	36	0.90
9	1.94	37	0.88
10	1.85	38	0.86
11	1.76	39	0.85
12	1.68	40	0.83
13	1.62	41	0.82
14	1.56	42	0.80
15	1.51	43	0.78
16	1.46	44	0.77
17	1.41	45	0.76
18	1.37	46	0.75
19	1.33	47	0.74
20	1.29	48	0.73
21	1.26	49	0.72
22	1.22	50	0.71
23	1.19	51	0.69
24	1.16	52	0.68
25	1.13	53	0.67
26	1.10	54	0.66
27	1.07	55	0.66
28	1.05	56	0.65
29	1.03	57	0.64
30	1.01	58	0.64
31	0.99	59	0.63
32	0.97	60	0.62