APPENDIX B

Point Source Times Series Production, Technical Memorandum, April 9, 2004.

2020 Facility Planning Project

TECHNICAL MEMORANDUM

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SUBJECT: Point Source Time Series Production

Introduction

As part of the Watershed/Watercourse Model Development for the MMSD 2020 Facilities Plan Project, pollutant loadings from Industrial Discharges, MMSD Combined Sewer Outfalls (CSO), and MMSD and local community Sanitary Sewer Outfalls (SSO) need to be derived for input into the HSPF model, using discharge data obtained from Triad. The purpose of this memorandum is to detail the steps taken to derive these loadings from Wisconsin Pollutant Discharge Elimination System (WPDES) permit data and CSO/SSO overflow event data.

CSO Time Series

Overview

1. MMSD overflow reports identified peak flow, average flow, volume overflow and duration of overflow information.
2. Events with missing flow, volume, or duration data were discarded.
3. Conversion of the recorded event data to a 15-minute interval flow time series established compatibility with the HSPF time series.
4. These derived flows were then applied to outfall pollutant concentrations, to generate a pollutant loading distribution for each overflow event.

Time Series Production

Before the simulated CSO time series could be produced a few general assumptions were outlined:

- A trapezoidal shape distribution was assumed to simulate the CSO time series.
  - The actual general outfall flow distribution increases to an early peak, followed by a decrease in flow to a constant level, which persists for the majority of the overflow event.
  - This initial peak was assumed negligible and eliminated from the simulated time series production, yielding a trapezoidal shape distribution.
- The peak flow, total volume, and duration of overflow were the independent variables in production of the time series.

   - Total volume and duration values were listed per overflow event. Each duration was rounded up to the nearest 15-minute increment.
   - Peak flow values were listed per day. For multiple day events, the largest daily peak flow was chosen for the time series production.

- Due to the assumed inaccuracy of the start dates for overflow events (different start dates, but same duration), all outfalls were assumed to start at the same time no matter their stated start date within the overflow event (i.e. within a 3-day overflow, an outfall with a stated start date on the second day was still assumed to start on the first day of the event).
   - For a specified overflow event, outfalls with the same recorded duration were assumed to start and stop in the same 15 minute intervals, allowing flows to be added cumulatively by interval
   - Outfalls with different recorded durations for a specific overflow event were still assumed to start in the same 15-minute intervals and continue through the end of the longest overflow duration. With these assumptions established, the point source time series distribution was produced for all outfalls exhibiting overflows during all overflow events.

1. A process similar to a synthetic unit hydrograph analysis was used to produce the distribution.
2. A general equation was developed to accommodate each outfall during all overflow events (see Attachment A for derivation of the general equation).
3. The time series of 15-minute interval flows was calculated using the general equation and three independent variables.
4. The time series plot varied depending on the input data. Some produced a trapezoidal shape, while others output only one peak 15-minute interval and a triangular shape (see Attachment A for sample tables and plots).
5. Only the 15-minute interval flow values were used to plot the data, resulting in a distorted hydrograph. Because a more refined graph, with a lower time interval was not used (it was not needed for the required data output), the exact start and end times are not plotted.

Once the time series was produced for each outfall, they were lumped by reach:

- All CSOs were located using GIS. These outfalls were plotted on a map with the designated reach breaks to determine which outfalls would be summed together. Because the exact location of discharge is known for each CSO, this method of summing can be used.
- For each overflow event, the final flow at each 15-minute time step is the sum of flows at all outfalls within the specified reach.
- There were a total of five final flow time series within the Menomonee and Kinnickinnic Watersheds, once all the outfalls were assigned to their designated reach. The lumped time series for outfalls located within the Milwaukee Watershed will be created once the subbasins and reach breaks are designated.
   - Menomonee Watershed: Reach 908 and Reach 922
   - Kinnickinnic River Watershed: Reach 806, Reach 807, and Reach 814
- Note that the Kinnickinnic HSPF model schematic has not been analyzed and restructured as the Menomonee has, so the reaches and reach breaks may change. However, the likelihood of changes occurring to the downstream reaches where the CSOs are located is minimal.
- Pollutant concentrations were applied to each lumped time series to produce pollutant-loading distributions for each overflow event. The concentrations used were acquired from the *CSO & SSO Concentrations for Purposes of Watercourse Modeling* memorandum.

SSO Time Series

Overview

1. MMSD overflow reports identified volume overflow and duration of overflow information. The local communities also report SSO total flow volumes and duration of overflows.
2. Events with missing volumes were discarded. Outfalls located outside the 2020 Facilities Planning Area and those that discharge directly to Lake Michigan were not evaluated
3. Conversion of the recorded daily data to a 15-minute interval flow time series established compatibility with the HSPF time series.
4. These derived flows were then applied to outfall pollutant concentrations, to generate a pollutant loading distribution for each overflow event.

Time Series Production

Before the simulated SSO time series could be produced a few general assumptions were outlined:

- Because the peak flow is not known as it is in the CSO overflow data set, an isosceles triangle shape distribution was assumed to simulate the SSO time series, instead of the trapezoidal shape distribution (see Attachment B for reasoning).
- The total volume and duration of overflow were the independent variables used for calculation of the peak flow and production of the time series. The duration was rounded up to the nearest 15-minute increment.
- All SSO overflow events had a maximum duration of 24 hours. Consecutive days with recorded overflow data were treated as individual events.
    - For a specified overflow event, outfalls with the same recorded duration were assumed to start and stop in the same 15 minute intervals, allowing flows to be added by interval
    - Outfalls with different recorded durations for a specific overflow event were still assumed to start in the same 15-minute intervals and continue through the end of the longest overflow duration. With these assumptions established, the SSO time series distribution was produced for all outfalls exhibiting overflows during all overflow events.

1. A process similar to a synthetic unit hydrograph analysis was used to produce the distribution.
2. A general equation was developed to accommodate each outfall during all overflow events (see Attachment B for derivation of the general equation).
3. Using the general equation and two independent variables the time series was produced, calculating 15-minute interval flows.
4. Note that the plotted hydrographs do not always accurately represent the continuous time series. If the peak flow did not occur at a 15-minute time step it is not represented in the plot, resulting in a distorted hydrograph. A more refined graph, with a lower time interval to ensure inclusion of the peak flow, was not needed for the required data output (see Attachment B for sample tables and plots).

Once the time series was produced for each outfall, they were lumped by reach:

- All SSOs were located using GIS. These outfalls were plotted on a map with the designated reach breaks to determine which outfalls would be summed together.
    - The designated GIS locations for SSOs do not consistently represent discharge locations; some may represent manholes or other SSO structures.
    - For this reason, a different method of summing must be used for SSOs.
        - All SSOs were categorized according to the subbasin in which they lie.
        - Subbasins were then lumped/summed according to the reach they routed through.

  - Intermittent streams were not used for routing. If an SSO routed through an intermittent reach (HSPF 2-digit reach), routing was continued to the nearest significant reach (HSPF 3-digit reach).
  - This process was completed using the HSPF Reach Schematic.

- For each overflow event, the final flow at each 15-minute time step is the sum of flows at all outfalls within the specified reach.
- There were a total of 16 final flow time series within the Menomonee Watershed, once all the outfalls were assigned to their designated reach.
- Note that the Kinnickinnic and Root River HSPF model schematics have not been analyzed and restructured as the Menomonee has. For this reason, the reach designations for the SSOs within the Kinnickinnic and Root Watersheds have not been completed.
- The lumped time series for the Milwaukee Watershed will be created once the subbasins and reach breaks are designated.
- There were numerous overflow events that did not have a specific location (multiple outfall listings or "various locations" were given as the location description). How to deal with these events, as far as lumping by reach, will have to be determined by the modelers.
- Pollutant concentrations were applied to each lumped time series to produce pollutant-loading distributions for each overflow event. The concentrations used were acquired from the *CSO & SSO Concentrations for Purposes of Watercourse Modeling* memorandum.

Industrial Discharge Pollutant Loading

Overview

1. All flow and concentration data was collected from the WDNR 2002/2003 data files. Facilities with missing concentration data were not discarded. However, discharge points located outside the 2020 Facilities Planning Study Area were discarded.
2. Conversion of the daily flows to 15-minute interval flows at each discharge point established compatibility with the HSPF time series.
3. Unlike the CSO and SSO time series, the industrial point source time series produces a constant 15-minute pollutant load (does not vary with time).

Time Series Production

Before the simulated industrial point source pollutant loading could be calculated a few general assumptions were outlined:

- As stated above, missing data was not discarded from the pollutant loading analysis.
  - Instead, the average concentration from all discharges with available data was input as the concentration and used to calculate the mass loading at each discharge point with missing data.
- The detection limit was used to calculate the mass loading at facilities when the recorded concentration in the Discharge Monitoring Report was stated to be below the detection limit. These detection limit values were included in the average concentration calculation mentioned above. Note that the detection limit for a specified pollutant may vary between facilities depending on the lab that conducted the testing.
- Discharge is assumed to occur 24 hours per day/365 days per year.

With these assumptions established, the pollutant loading was calculated for all industrial discharges.

1. The average daily flow was calculated by taking the average of the 4 quarterly flow values, which are represented in gallons per day. This value was then converted into a 15-minute flow rate.

2. The 15-minute flow and concentration values at each discharge point were then multiplied and converted into a mass-loading rate (lbs/15-minutes).
3. Note that this mass-loading rate is constant, it does not change with time or event as the CSO and SSO discharge loadings do.

Once the time series was produced for each facility discharge point, they were lumped by reach:

- All industrial point sources were located, using street maps, according to street addresses designated on each WPDES permit.
  - Due to the uncertainty of the location of each discharge point in relation to the street address of the facility, the method of summing by subbasin was used for the industrial point sources.
    - All industrial discharges were categorized according to the subbasin in which they lie using topographic maps.
    - Subbasins were then lumped/summed according to the reach that they routed through.
    - Intermittent streams were not used for routing. If an industrial facility discharge routed through an intermittent reach (HSPF 2-digit reach), routing was continued to the nearest significant reach (HSPF 3-digit reach).
    - This process was completed using the HSPF Reach Schematic.

- Note that the Kinnickinnic and Oak Creek HSPF model schematics have not been analyzed and restructured as the Menomonee has. For this reason, the reach-by-reach designations for the industrial point sources within the Kinnickinnic and Oak Creek Watersheds have not been completed.
- The lumped time series for the Milwaukee Watershed will be created once the subbasins and reach breaks are designated.

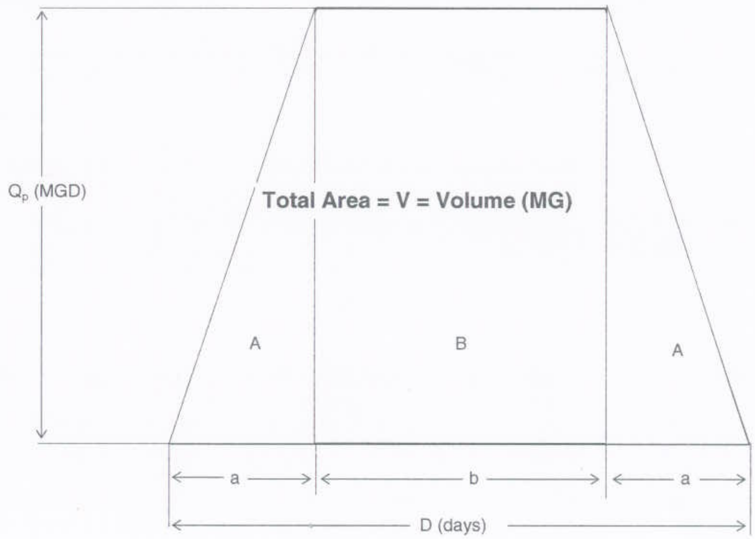
Attachment A -

CSO

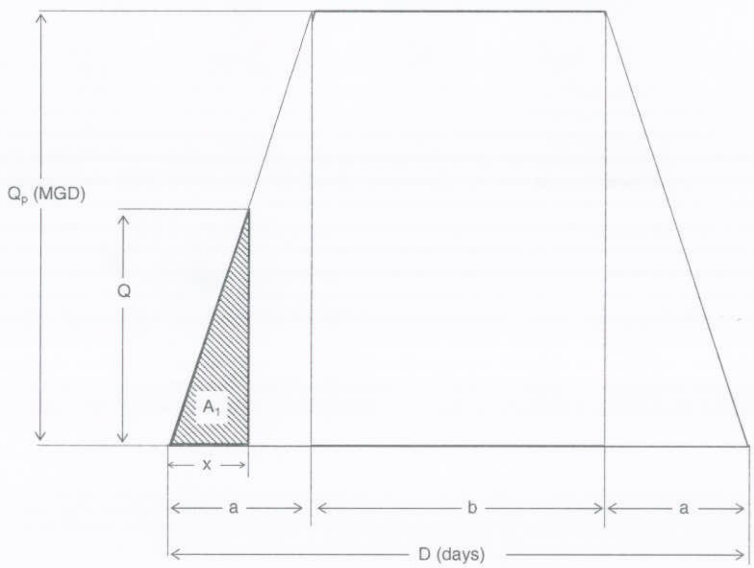
Derivation of the General Equation

Sample Tables and Plots

Derivation of General Equation:



(sample time-series distribution)



(set-up for equation calculations)

Calculations:

- use a method of ratios and an adjustment of units to determine the interval flow

$Q_p = \sqrt{3}*a$ *(days)*

$A = (1/2)*a*(\sqrt{3}a) = (\sqrt{3}/2)*a^2$ *(days²)* also: $A = (1/2)*Q_p*a$ *(MG)*

$Q = \sqrt{3}*x$ *(days)*

$A_1 = (1/2)*x*(\sqrt{3}x) = (\sqrt{3}/2)*x^2$ *(days²)* also: $A_1 = (1/2)*Q*x$ *(MG)*

$$\frac{(\sqrt{3}/2)*a^2 \ (days^2)}{A \ (MG)} = \frac{(\sqrt{3}/2)*x^2 \ (days^2)}{A_1 \ (MG)}$$

$$A_1 = \frac{A*x^2}{a^2} = \frac{(1/2)*Q_p*a*x^2}{a^2} = (1/2)*Q*x \ (MG)$$

(1) →

$$\mathbf{Q = \frac{Q_p*x}{a}} \quad (x \le a)$$

$$\mathbf{Q = Q_p} \quad (a<x<(a+b))$$

$$\mathbf{Q = \frac{Q_p*(D-x)}{a}} \quad (x \ge (a+b))$$

$V = 2A+B = Q_p*a+Q_p*b = Q_p(a+b)$

$D = 2a+b$

$b = D-2a$

$V = Q_p(a+(D-2a)) = Q_p(D-a)$

(2) →

$$\mathbf{a = D - \frac{V}{Q_p}} \quad (b>0)$$

$$\mathbf{a = b/2 + D - \frac{V}{Q_p}} \quad (b \le 0)$$

(3) →

$$\mathbf{b = \frac{2*V}{Q_p} - D}$$

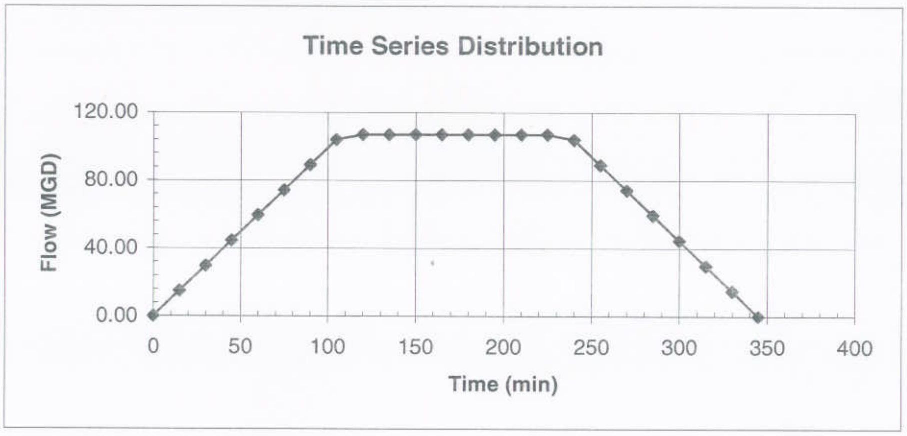
NOTE:

- the flow equation was only designed to calculate values on the ascending limb, the second and third equations are an adjustment of this equation to produce the desired shape.
- the second equation to determine a is necessary to ensure that all three criteria are met (peak flow, duration, and volume).

Sample Tables and Plots:

Trapezoidal shape (Outfall #90, 8/12/02 storm)

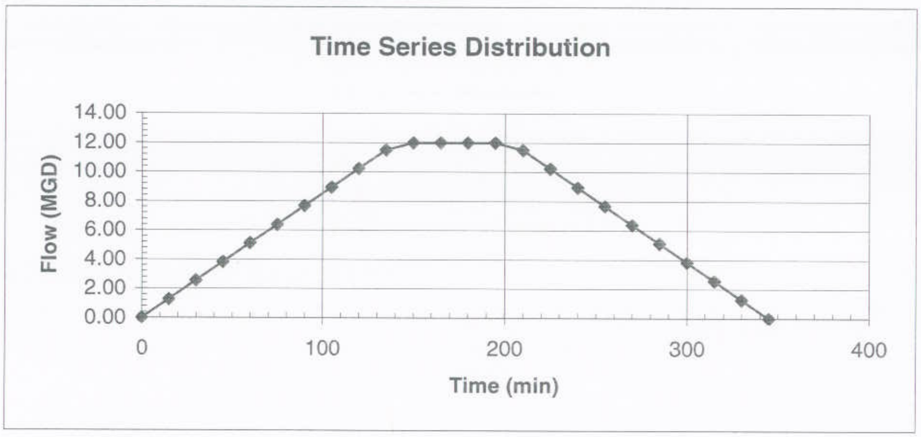
Duration	5.75 hours
	0.24 days
Volume	17.60 MG
Peak Flov	107.00 MGD
a	0.08 days
	108.14 min
b	0.09 days
	128.72 min
a+b	0.16 days
	236.86 min



Time (min)	Time (days)	Flow (MGD)
0	0.0000	0.00
15	0.0104	14.84
30	0.0208	29.68
45	0.0313	44.53
60	0.0417	59.37
75	0.0521	74.21
90	0.0625	89.05
105	0.0729	103.89
120	0.0833	107.00
135	0.0938	107.00
150	0.1042	107.00
165	0.1146	107.00
180	0.1250	107.00
195	0.1354	107.00
210	0.1458	107.00
225	0.1563	107.00
240	0.1667	103.89
255	0.1771	89.05
270	0.1875	74.21
285	0.1979	59.37
300	0.2083	44.53
315	0.2188	29.68
330	0.2292	14.84
345	0.2396	0.00

Trapezoidal shape (Outfall #91, 8/12/02 storm)

Duration	5.75 hours
	0.24 *days*
Volume	1.70 MG
Peak Flov	54.00 MGD
a	0.12 days
	172.50 min
b	-0.18 days
	-254.33 min
a+b	0.12 days
	172.50 min



Time (min)	Time (days)	Flow (MGD)
0	0.0000	0.00
15	0.0104	1.28
30	0.0208	2.55
45	0.0313	3.83
60	0.0417	5.11
75	0.0521	6.38
90	0.0625	7.66
105	0.0729	8.94
120	0.0833	10.21
135	0.0938	11.49
150	0.1042	12.00
165	0.1146	12.00
180	0.1250	12.00
195	0.1354	12.00
210	0.1458	11.49
225	0.1563	10.21
240	0.1667	8.94
255	0.1771	7.66
270	0.1875	6.38
285	0.1979	5.11
300	0.2083	3.83
315	0.2188	2.55
330	0.2292	1.28
345	0.2396	0.00

Attachment B -

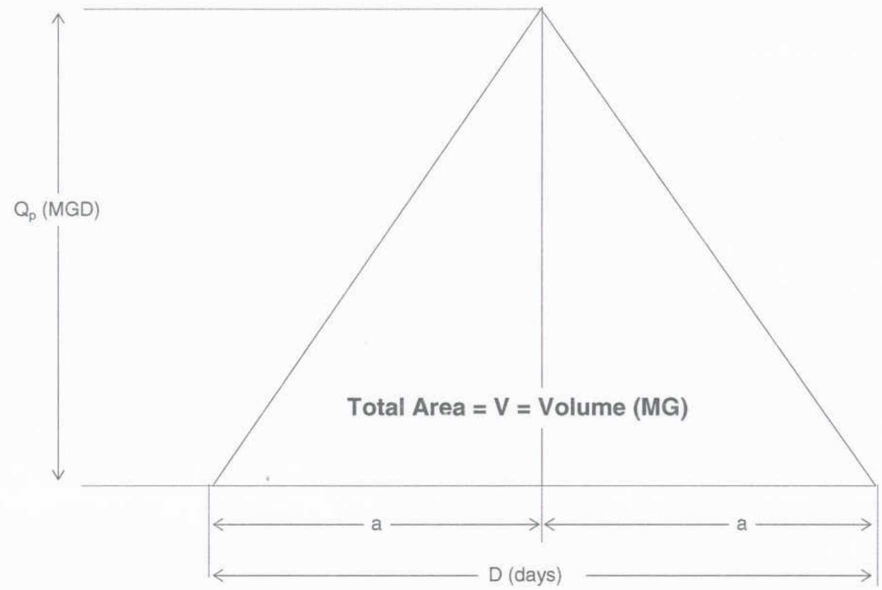
SSO

Derivation of the General Equation

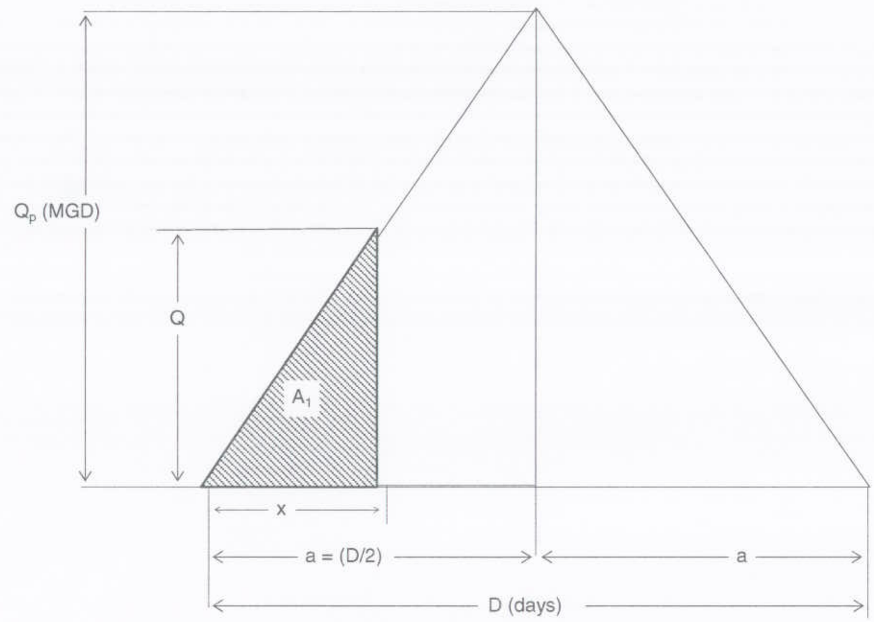
Sample Tables and Plots

Derivation of General Equation:

NOTE: because Q_p is not known, an isosceles shape is used instead of a trapezoid (see calculations below).



(sample time-series distribution)



(set-up for equation calculations)

Calculations:

- use a method of ratios and an adjustment of units to determine the interval flow

$(1/2)*V = (1/2)*((1/2)*D)*(Q_p))$ (4) ⟶ $Q_p = (2V/D)$

NOTE:

- because peak flow is calculated in this manner, substitution into the equation for b (Appendix A, (3)) yields a value of zero and a triangle distribution.
- substitutions were made in the calculations below for the a and Q_p variables (using eqation (2)-Appendix A and equation (4).

$Q_p = \sqrt{3}*(D/2)$ *(days)*

$A = (1/2)*(D/2)*(\sqrt{3}(D/2)) = (\sqrt{3}/8)*D^2$ *(days²)* also: $A = (1/2)*V$ *(MG)*

$Q = \sqrt{3}*x$ *(days)*

$A_1 = (1/2)*x*(\sqrt{3}x) = (\sqrt{3}/2)*x^2$ *(days²)* also: $A_1 = (1/2)*Q*x$ *(MG)*

$$\frac{(\sqrt{3}/8)*D^2 \ (days^2)}{(V/2) \ (MG)} = \frac{(\sqrt{3}/2)*x^2 \ (days^2)}{(1/2)*Q*x \ (MG)}$$

(5) ⟶

$$Q = \frac{4*x*V}{D^2} \quad (x<a)$$

$$Q = Q_p \quad (x=a)$$

$$Q = \frac{4*V*(D-x)}{D^2} \quad (a<x<D)$$

NOTE:

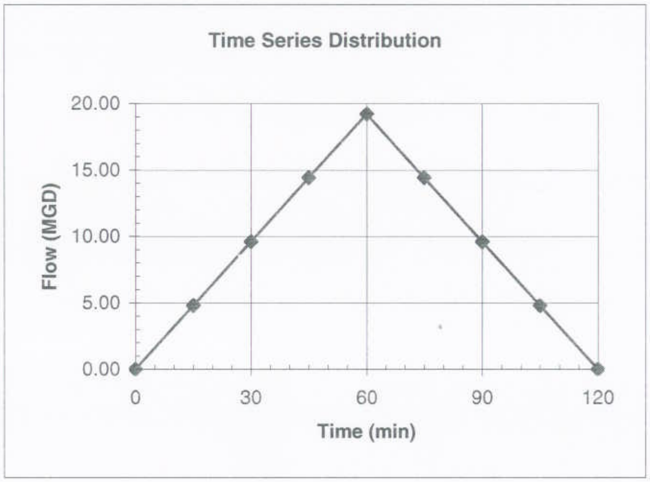
- the flow equation was only designed to calculate values on the ascending limb, the second and third equations are an adjustment of this equation to produce the desired shape.

Sample Tables and Plots:

Triangular shape w/ peak at 15-minute increment (Outfall #207, 8/6/98 storm)

Duration	2.00	hours
	0.08	*days*
Volume	0.80	MG
Peak Flow	19.20	MGD

Time (min)	Time (days)	Flow (MGD)
0	0.0000	0.00
15	0.0104	4.80
30	0.0208	9.60
45	0.0313	14.40
60	0.0417	19.20
75	0.0521	14.40
90	0.0625	9.60
105	0.0729	4.80
120	0.0833	0.00



Distorted shape (trapezoidal) - Peak NOT at 15-minute increment (Outfall #207, 4/11/95 storm)

Duration	1.75	hours
	0.07	*days*
Volume	0.39	MG
Peak Flow	10.59	MGD

Time (min)	Time (days)	Flow (MGD)
0	0.0000	0.00
15	0.0104	3.02
30	0.0208	6.05
45	0.0313	9.07
60	0.0417	9.07
75	0.0521	6.05
90	0.0625	3.02
105	0.0729	0.00