Continuous Simulation for Hydro-sustainability Analysis

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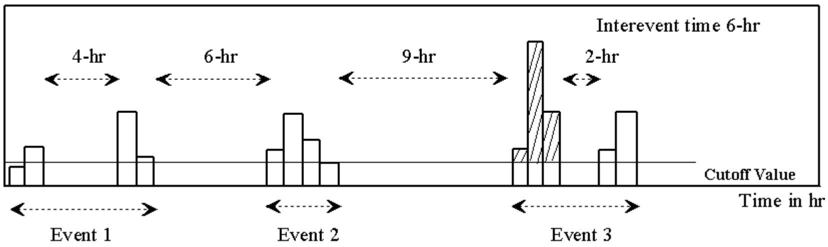
WQ Basins and Wetland Growth

A micro pool or wetland is often a desirable element in a storm water detention system. The event-based approach provides the design information to size a pond for the selected risk such as the10-yr allowable release for the low flow orifice and the 100-yr allowable for the high flow outlet. These extreme-event based designs do not warrant that the random rainfall pattern can meet the seasonal needs for vegetation and wetland. As a result, many wetland areas turn into an eyesore.

How to estimate the long-term runoff sustainability to the wetland is the key issue.

Structure of Continuous Record



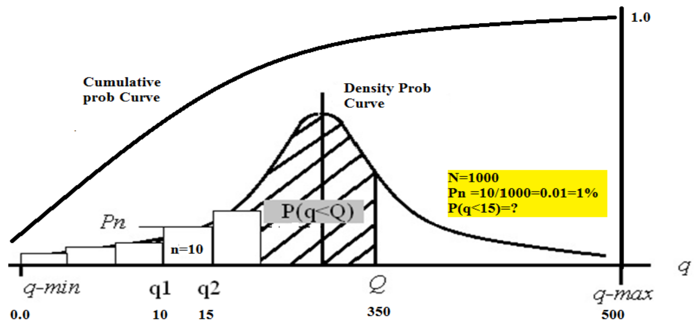
- A continuous record covers a period of time from T1 to T2.
- A MIT of 6, 12, 24, 48 hours is used to separate the continuous record into individual events
- Duration for an event begins from the cutoff value on the rising hydrograph or hyetograph to the cutoff value on the recession. Events in a month begins from the first rain block to the end of the last rain block for each calendar month

Hydro Data Base
Derived from a Continuous Record

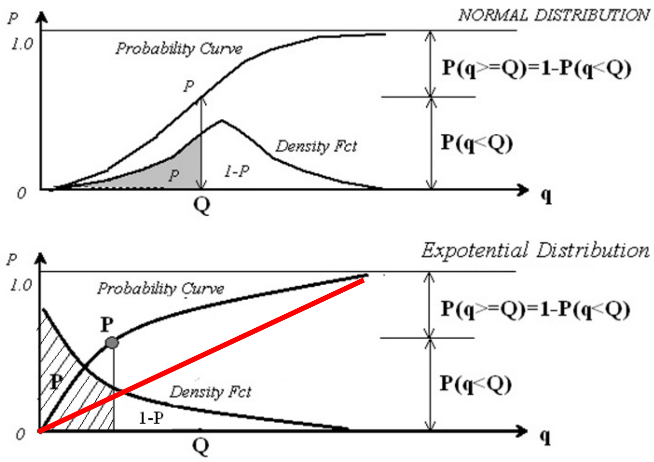
- **Random Variables**
  Rainfall, Runoff, Water Depth, Temperature,
- **Continuous Record**
  Wet period = rain blocks in 15, 30 or 60 min
  Dry period = Inter-event Time (IT)
  Database generated for the Selected IT
  Min IT (MIT) to separate a continuous record into single events
  Often MIT=12, 24, or 48 hr, depending on basin's drain time.
- **Complete Data Base**
  All events are included (cutoff value=0)
  Partial Duration Data Base
  All events>cutoff value are included (cutoff=0.1 inch)
- **Annual Max Series** (AMS)
  Only the highest one in each year is included.
- **Annual Exceedance Series** (AES)
  Only hose events>cutoff value up to the number of years in the record are included.

Basics of Probability Curve

1. Population and Sample
2. Density Pn= n / N
   - n= number of outcomes within q1 and q2
   - N=total number of tests
1. Probability
   P(q=Q)=0 (for a given value)
   P(q<Q) = non-exceedance prob and P(q>=Q) = exceedance prob

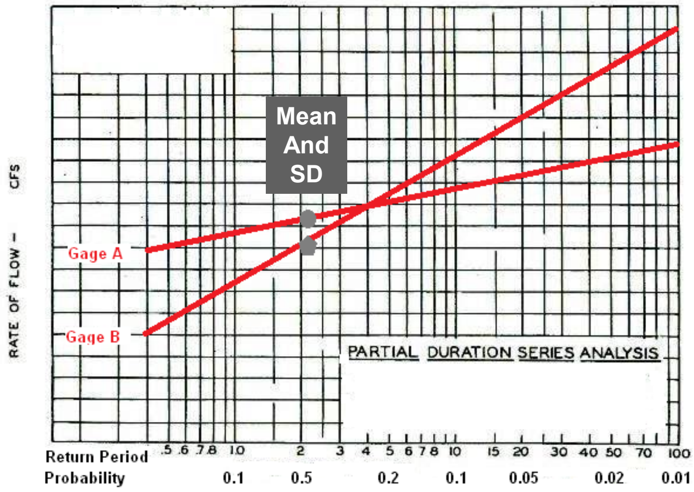


Density and Cumulative Probability Curves



The area under the density curve is unity.
The cumulative curve is between 0 and unity.
How to adjust the probabilistic scale to make the cumulative curve a straight line?

Graphic Paper with the underlying prob scale



1. **to convert a cumulative probability curve into a straight line on the graphic paper**
2. **to eyeball if the sample plotted on the graphic paper behaves as a straight line.**
3. **If so, to extrapolate the line for predictions of extreme events**
4. **What is the difference between Gage A data and Gage B data? Mean and SD**

Statistics at Station – SYSTEM STATISTICS

Mean, standard deviation and skewness of variable, *q(i)*, are computed as:

$$\overline{Q} = \frac{1}{n}\sum_{i=1}^{i=n} q(i)$$

$$S = \sqrt{\frac{1}{n-1}\sum_{i=1}^{i=n}\left(q(i)-\overline{Q}\right)^2}$$

$$g = \frac{1}{S^3}\frac{n}{(n-1)(n-2)}\sum_{i=1}^{i=n}\left(q(i)-\overline{Q}\right)^3$$

Using logarithmic values, the above equations are converted to

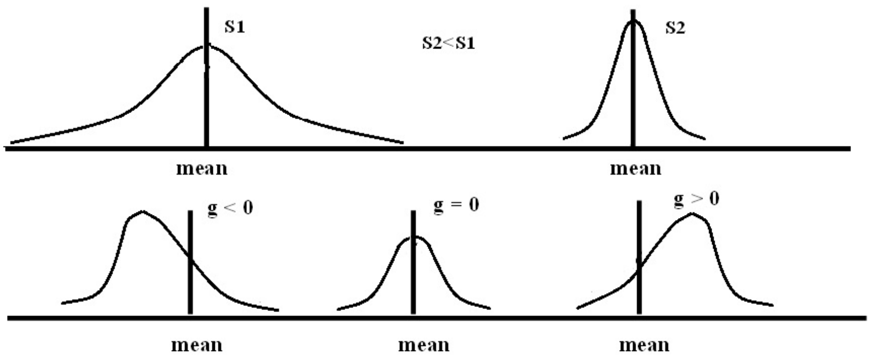
$$\overline{Q_{\log}} = \frac{1}{n}\sum_{i=1}^{i=n} Log\ \ q(i)$$

$$S_{Log} = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{i=n}[Logq(i)-\overline{Q_{Log}}]^2}$$

$$g_{Log} = \frac{1}{S_{Log}{}^3}\frac{n}{(n-1)(n-2)}\sum_{i=1}^{i=n}[Logq(i)-\overline{Q_{Log}}]^3$$

Distributions identified with means and SD

Statistics for a random variable = Mean, SD, and Skewness Coefficient
***The outcomes for q(i) are* illustrated as:**



Example for Mean and SD

Rank	Ranked Data Q AMS	AMS SD Moment	AMS Skew Moment
1	596.000	16623.8044	2143362.5197
2	591.000	15359.4711	1903550.4530
3	557.000	8088.0044	727381.1997
4	549.000	6713.0711	550024.2930
5	544.000	5918.7378	455348.2264
6	534.000	4480.0711	299866.0930
7	524.000	3241.4044	184543.9597
8	507.000	1594.6711	63680.5330
9	505.000	1438.9378	54583.7064
10	505.000	1438.9378	54583.7064
11	416.000	2607.8044	-133171.8803
12	414.000	2816.0711	-149439.5070
13	390.000	5939.2711	-457719.8270
14	374.000	8661.4044	-806088.0403

Statistics at Gage Station

Mean	467.0667		
SD		77.8835	
SkewCoeff			0.8532

Flood-Flow Plotting Formula

A Plotting Formula is to convert the **m-th magnitude** among **M observations in N periods** into its non-exceedance probability. Knowing the pairs: (magnitude, probability) we shall be able to select a probability model based on the best fit.

P(Q>=q)=(m-a)/(M+1-2a) (Exceedance Prob)
P(Q>=q)=m/(M+1) if a = 0 (Exceedance Prob)

a = 0.00 for Weibull *a = 0.30 for Median/Beard*
a = 0.375 for Blom a = 0.4 for Cunnane
a = 0.44 for Gringorten

For instance, In a 20-yr record, Q=100 cfs is ranked 60 out of 100 events (N=20*12 =240 months , let *a=0, m=60 and M=100*):

(a) P(Q>=100 cfs)= m/(M+1)=60/101=0.60
(b) P(Q<100 cfs) = 1-0.6 = 0.40
(c) A chance of 60% to exceed the magnitude or 100 cfs.

Flood Flow Return Period

- **Definition**
  Recurrence Period = time period between two occurrences
  Return Period = the long term average time period of recurrence.

- **Empirical Formula:**
  (1) rank M events in a descending order
  (2) m-th magnitude out of M events in N periods (months or years)

Tr= (N+1-2a)/(m-a) *in which a=constant.* ***Tr= (N+1)/m when a=0***

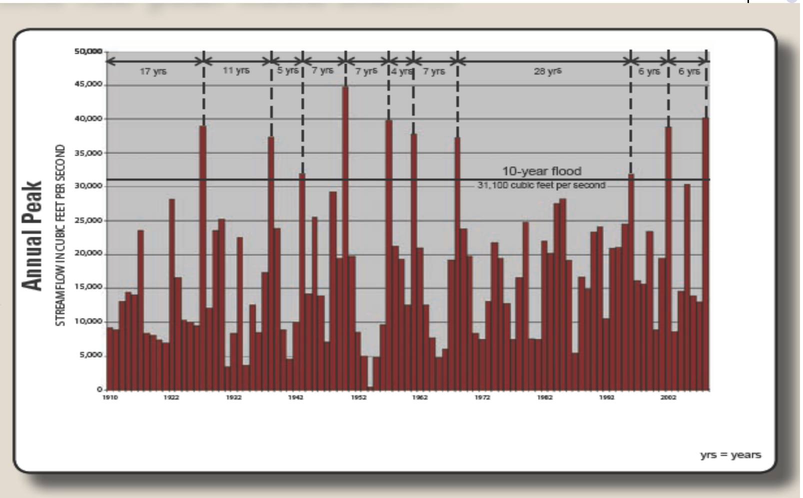
Exceedance Probability: ***P(Q>=q)=(m-a)/(M+1-2a)***

For instance, in a 20-yr record, the probability for the highest magnitude out of 50 events is: (N=20 and M=50)

(a) The return period the highest (m=1) is
*Tr=(20+1-2*0.4)/(1-0.4)=33.7 years (a=0.4) or Tr=21 (a=0)*
*(b) P(Q>=q)=(1-0.4)/(50+1-2*0.4)= 0.012 (a-0.4) or P=0.0476 (a=0)*

FLOOD FLOW Return Period

Recurrence Period = time period between two occurrences
Return Period = the long term average time period of recurrence.



Incidence of the 10-year flood for the Embarras River at Ste. Marie, IL (03345500). The variability in time between "10-year floods" ranges from 4 to as many as 28-years between floods.

Generalized Probability for Flood-Flow Distribution

Gumbel, Exponential, Normal, and Pearson Ty 3
for real and log values

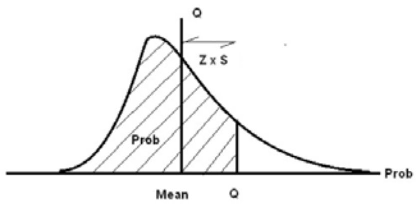
General Probability Equation is described as:

$$Q = \overline{Q} + Z(T_r)S \qquad \text{(a linear equation Y= a +b X)} \qquad (4.11)$$

For logarithmic values, Eq 4.11 is converted to:

$$LogQ(T_r) = \overline{Q_{Log}} + Z(T_r)S_{Log} \qquad (4.12)$$

The value of frequency factor depends on the underlying probability distribution and the return periods.



Exponential Distribution

$$Z_e(T_r) = \frac{\sqrt{6}}{\pi}(\ln T_r - 0.5772) \quad \text{for all Tr>0}$$

$$Q = \overline{Q} + Z_e(T_r)S$$

Z_e = Exponential frequency factor for return period T_r.

Gumbel Distribution

$$Z_g(T_r) = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \ln\left[\ln\frac{T_r}{(T_r - 1)}\right]\right\} \quad \text{for all Tr>1 year}$$

$$Q = \overline{Q} + Z_g(T_r)S$$

$Z_g(T_r)$ = Gumbel frequency factor for return period T_r, and $\pi = 3.1416$.

Frequency Factors

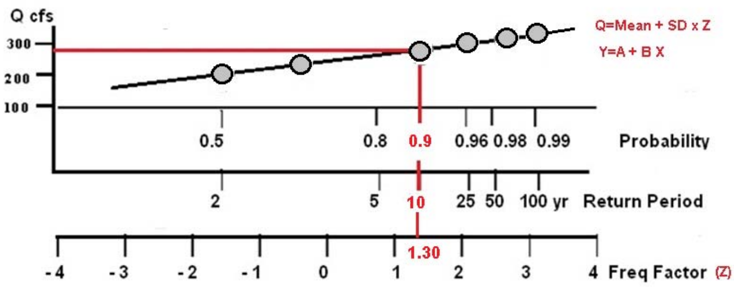
	Tr	Frequency	Factor
P(q>=Q)	Years	Gumble	Expon
0.20	500.00	4.395	4.395
0.50	200.00	3.679	3.681
1.00	100.00	3.137	3.141
2.00	50.00	2.592	2.600
5.00	20.00	1.866	1.886
10.00	10.00	1.305	1.345
20.00	5.00	0.719	0.805
50.00	2.00	-0.164	0.090
80.00	1.25	-0.821	-0.276
90.00	1.11	-1.100	-0.368
95.00	1.05	-1.306	-0.410
99.00	1.01	-1.641	-0.442

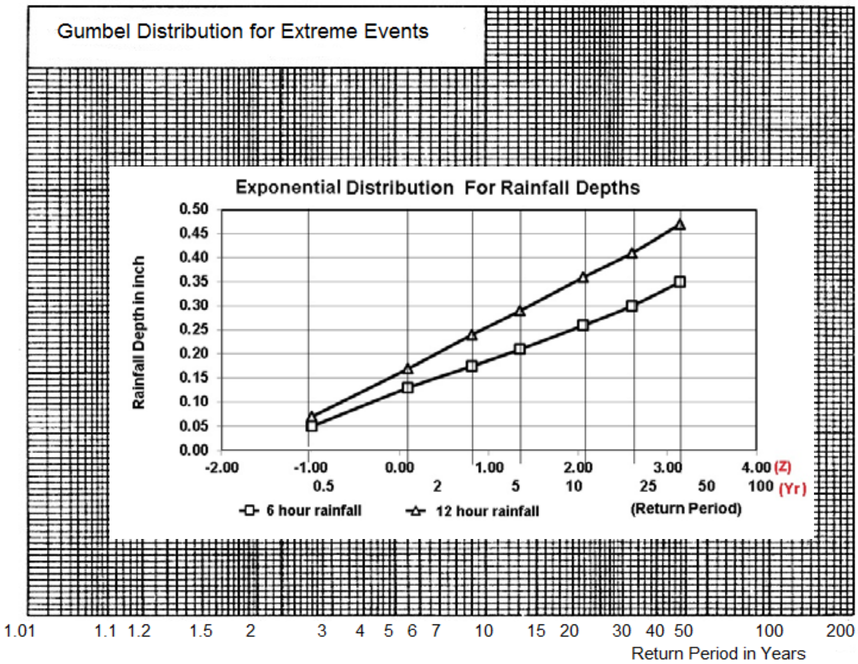
$$Q = \overline{Q} + S \times Z(T_r)$$
$$Y = A + B\,X$$

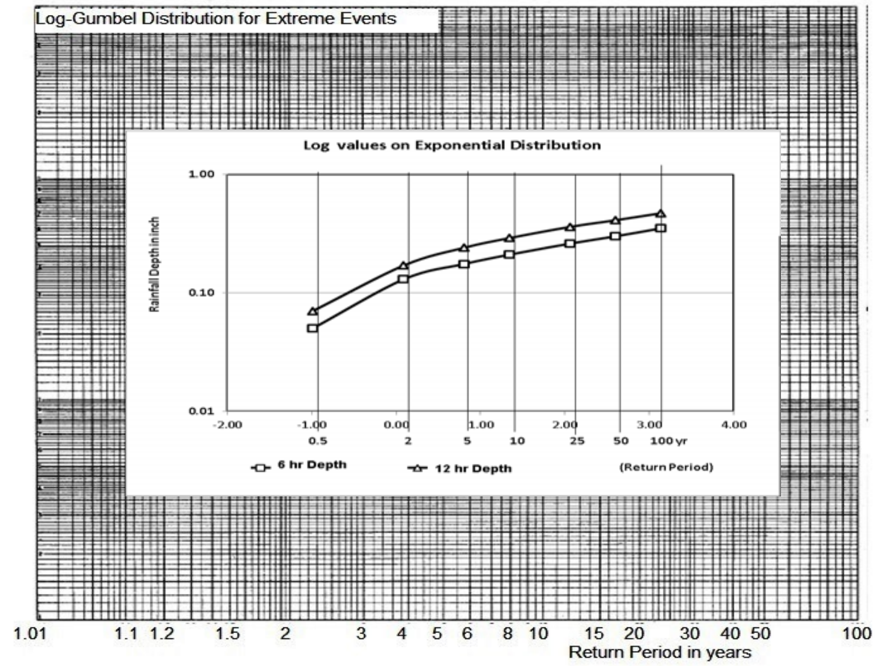
Q is linear with respect to Z
Y is linear with respect to X.

<u>Gumbel Graphical Paper</u> is prepared with variable magnitudes on the y-axis, and frequency factors, Z_g, on the x-axis. The value of Z_g can be generated as:

Tr	Z_g	P(q>=Q)	P(q<Q)
2.00	- 0.164	0.50	0.50
5.00	0.719	0.20	0.80
10.00	1.304	0.10	0.90
25.00	2.044	0.04	0.96
50.00	2.592	0.02	0.98
100.00	3.137	0.01	0.99



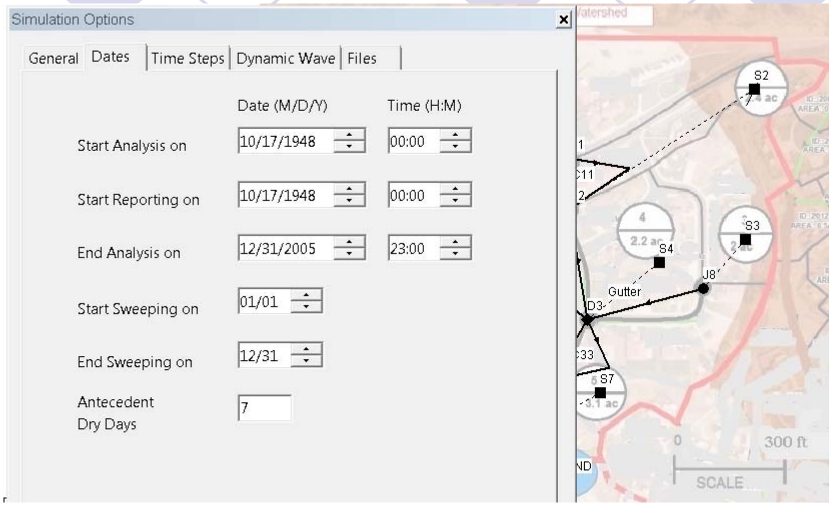




Frequency Analyses In EPA SWMM

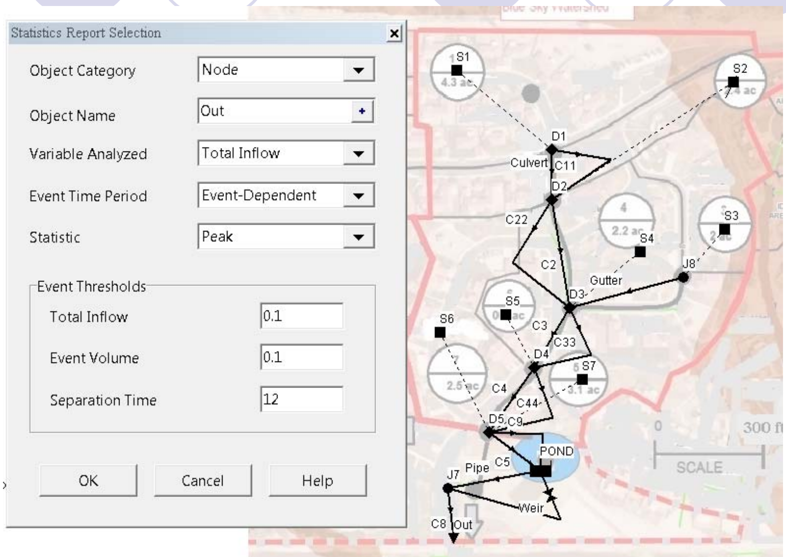
- **Variables**:
  depth, volume, inflow, peak flow
- **Time period**:
  event, daily, monthly, annual
- **Statistics**:
  average, highest, total, duration, IT.
- **Cutoff (Threshold) value**:
  flow, volume, depth, and MIT
- **Report**
  mean, SD, and skewness coefficient,
- **Table**
  frequency distribution for all events>cutoff value
- **Plots**
  histogram and frequency curve for all events>cutoff

Project Blue Sky Development- **Continuous Simulation** using one-hr precipitation depths from 1948 to 2995



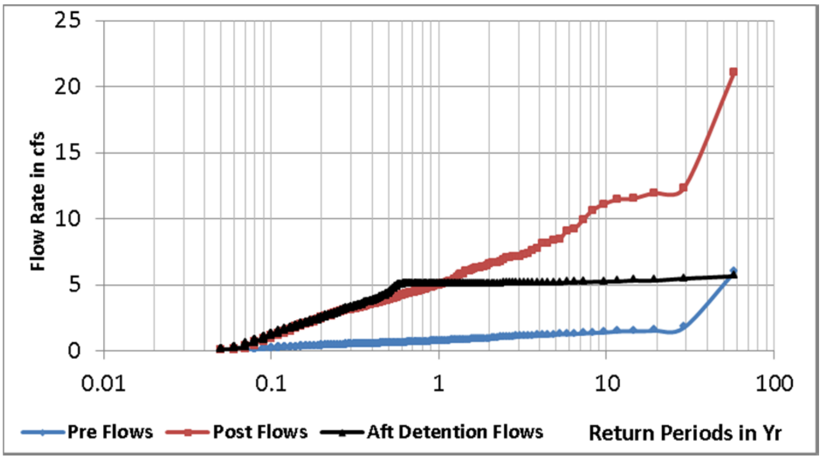
Use Δt=3600 seconds for computations

Statistical Analysis in SWMM

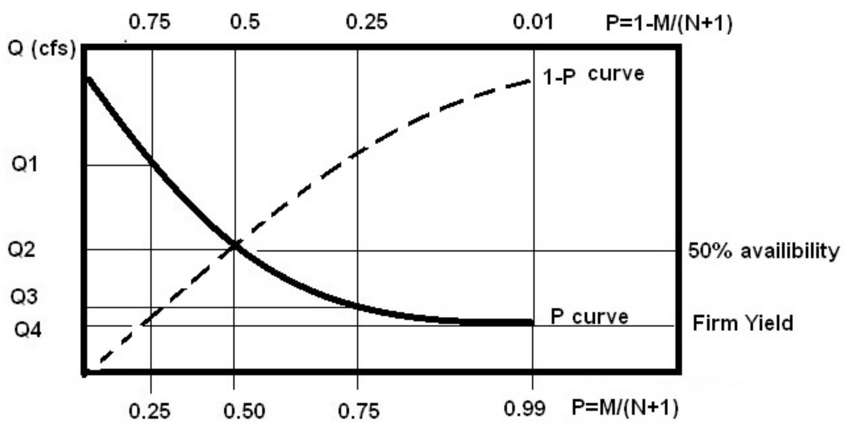


PROEJCT: BLUE SKY DEVELOPMENT

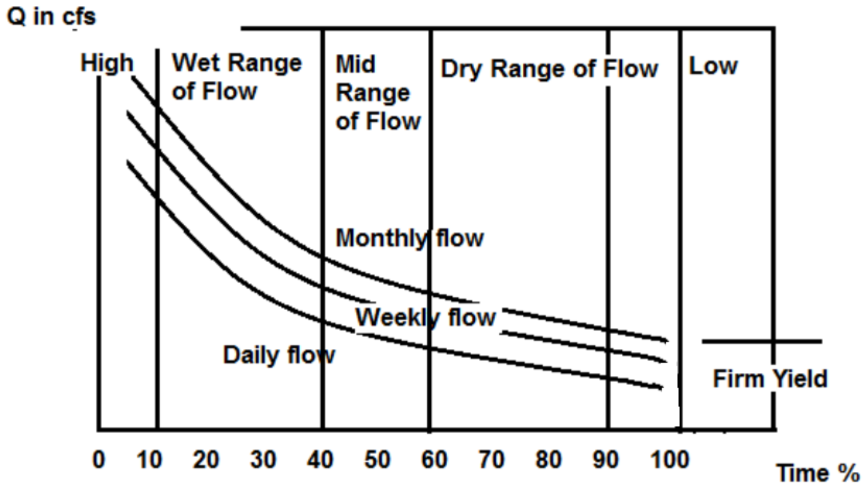
1. Good control for extreme flows (Q50 to Q100)
2. Fair control for 1-yr to 50-yr flows (Q1 to Q50)
3. No control for events <Q1



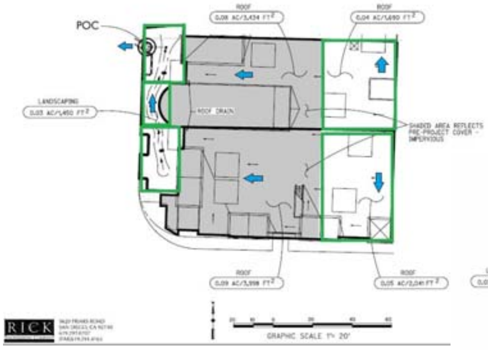
Flow Duration Curve (time%>Q)

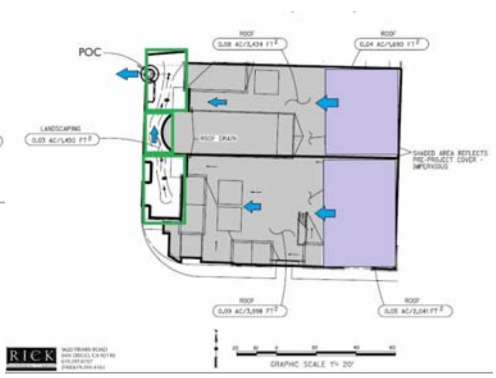


Flow Duration Curves for flow variables

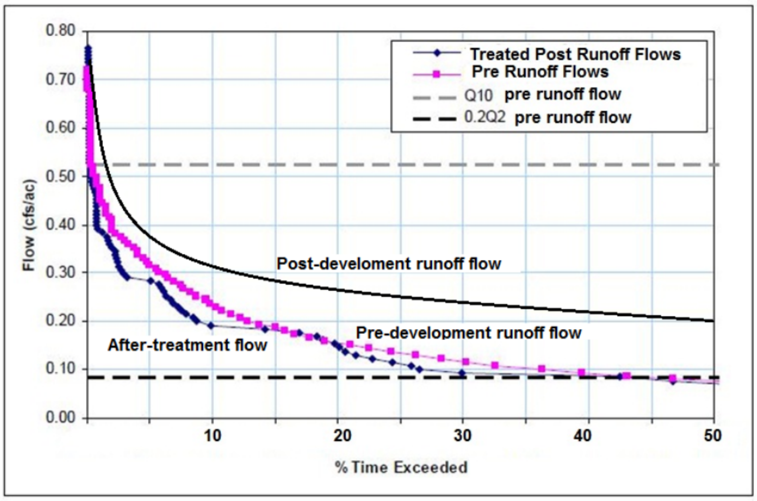


An existing roof of 0.17 acre is expanded into the back yard. The impact on the runoff increase will be mitigated with a 100-sq feet rain garden to be intalled in the front yard. Evaluate the effectiveness of the proposed rain garden using the pre- and post- flow duration curves. Hint: Preservation of flow regime is defined by the flow duration curve between 0.2* Q2 and Q10.





Using the 30-yr continuous rainfall record observed near the project site, the performance for the proposed LID treatment is analyzed with EPA SWMM5 as:



Continuous Model

More Information

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WWW.UCDENVER.EDU/~Jguo -- Website

WWW.UDFCD.ORG -- Free Software

WWW.URBANWATERSHEDS.ORG – Training Classes

Outlier in a Statistical Analysis