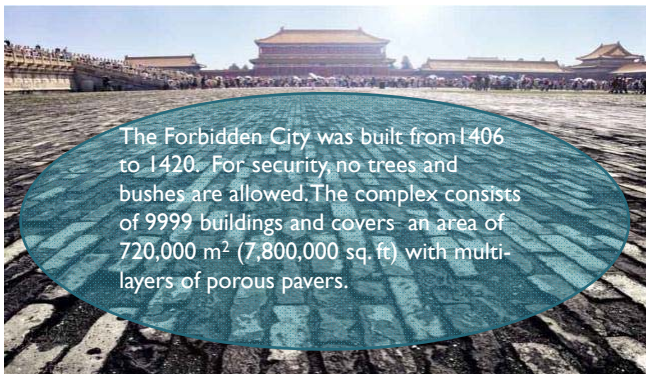
Case Study of LID Designs



James C.Y. Guo, PhD and PE, Professor and Director,
Hydrology and Hydraulics, Civil Engineering,
U. of Colorado Denver

On June 23, 2011, the City of Beijing was severely flooded. The forbidden city was also soaked, but drained well. Why?

GOALS FOR HYDROLOGIC STUDY

Watershed Flood Mitigation Criteria

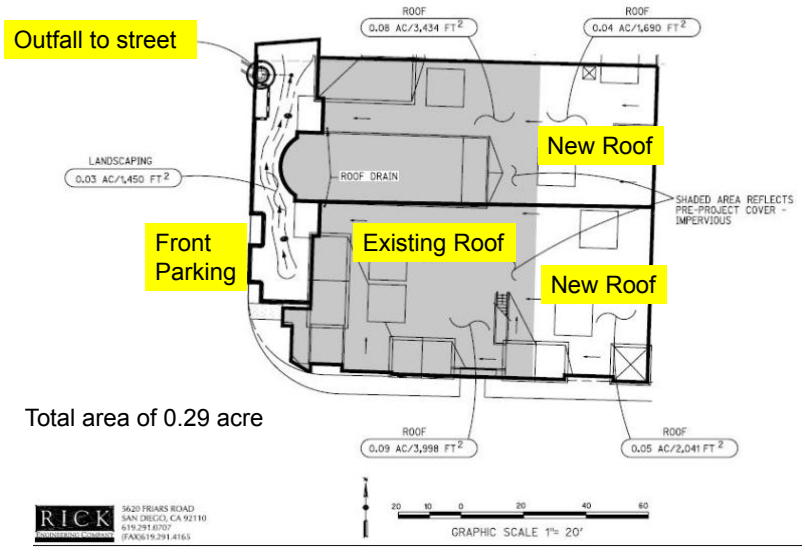
1. Separate storm events within the continuous record
2. Determine extreme events including 85th and 95th rainfall depths
3. Plot flow-frequency relationship
4. Plot flow-duration relationship
5. Model detention mitigation to reduce peak flows
6. Model LID mitigation to reduce runoff volumes
7. Determine the post-project peak flows ≤ pre-project peak flows

Watershed Regime Preservation Criteria:

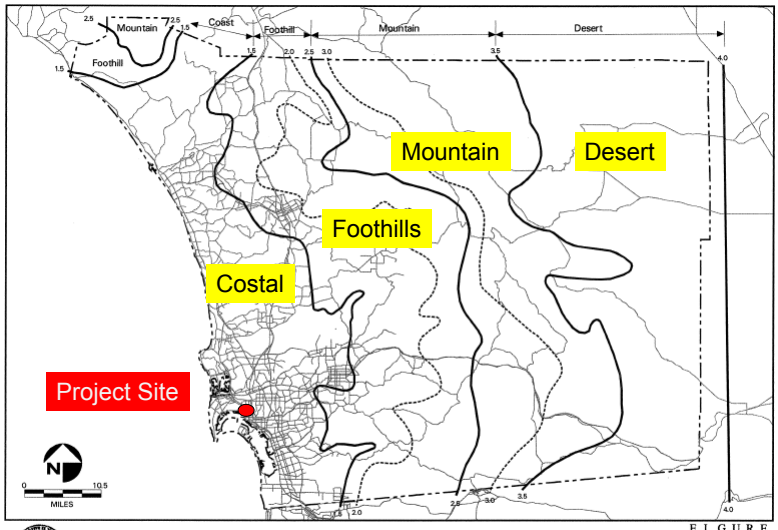
(1)The post-project flows need to be slightly < the pre-project flows
- (1-1) for extreme events≥ the 85th storm
- (1-2) for a range from 0.1Q2 to Q10.

(2) The post-project total number of hours of flow < the pre-project condition
- (1-1) between 0.1Q2 and Q10

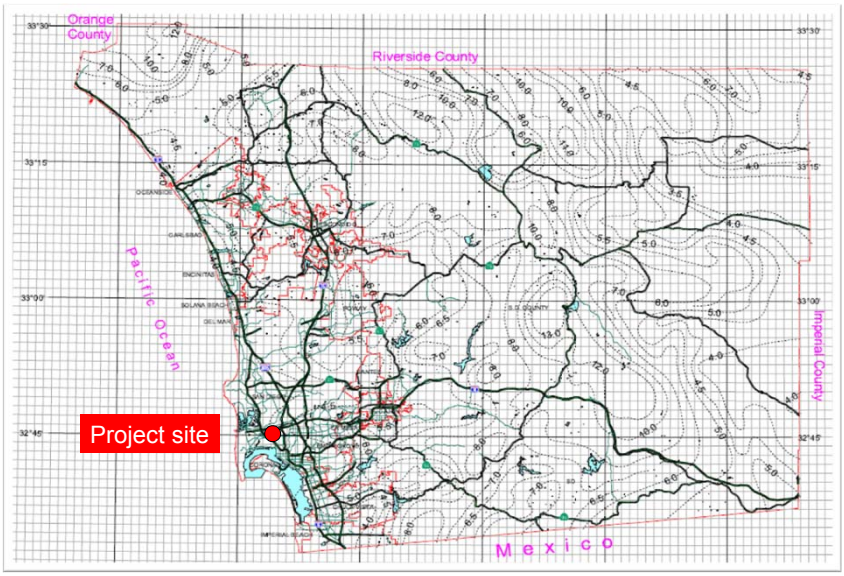
Stormwater LID Mitigation of New Roof San Diego, CA



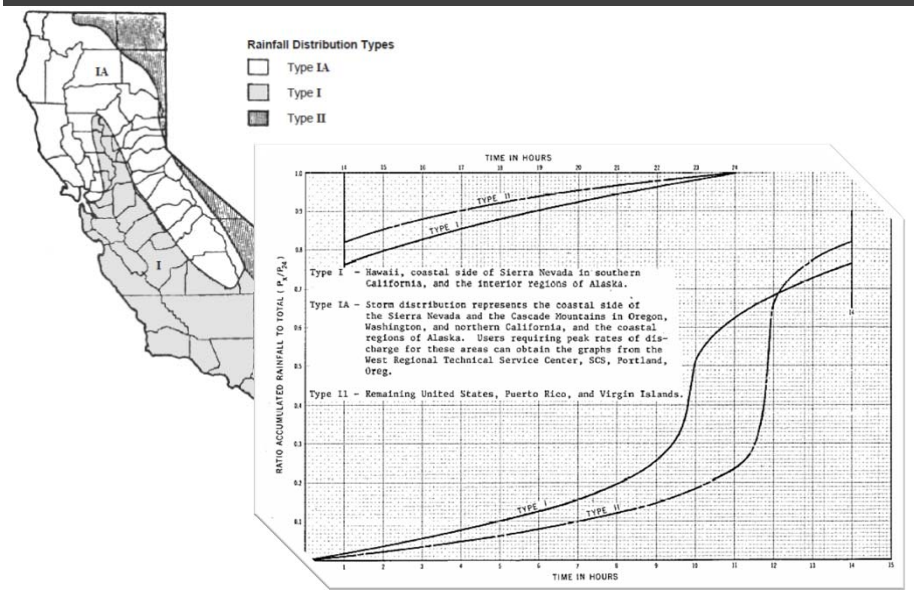
Precipitation Zones, San Diego, CA



Design Rainfall Depths, San Diego, CA
6-hr and 24-hr, 2- to 100-yr events



Design Rainfall Distribution – SCS 24-hr Type I
San Diego, CA



One-hr Continuous Rainfall Record at project site

HOW TO CONVERT SD RAINFALL CONTINUOUS RECORD INTO SWMM INPUT FILE

Place the cursor below the Yellow Cell to paste the SD Rainfall File

Month	Day	Year	Hour	P depth	Unit	Gage	SWMM	Input for	Rain
Paste below							Date	Hour	Depth(in)
10	17	1948	8	0.05	in	CCDA Lindbergh	10/17/1948	8:00	0.05
10	17	1948	9	0.05	in	CCDA Lindbergh	10/17/1948	9:00	0.05
10	17	1948	17	0.01	in	CCDA Lindbergh	10/17/1948	17:00	0.01
10	17	1948	20	0.04	in	CCDA Lindbergh	10/17/1948	20:00	0.04
10	17	1948	22	0.02	in	CCDA Lindbergh	10/17/1948	22:00	0.02
10	17	1948	23	0.02	in	CCDA Lindbergh	10/17/1948	23:00	0.02
10	18	1948	1	0.01	in	CCDA Lindbergh	10/18/1948	1:00	0.01
10	18	1948	2	0.06	in	CCDA Lindbergh	10/18/1948	2:00	0.06
10	18	1948	3	0.11	in	CCDA Lindbergh	10/18/1948	3:00	0.11
10	18	1948	4	0.19	in	CCDA Lindbergh	10/18/1948	4:00	0.19
10	18	1948	5	0.25	in	CCDA Lindbergh	10/18/1948	5:00	0.25
10	18	1948	6	0.12	in	CCDA Lindbergh	10/18/1948	6:00	0.12
10	18	1948	7	0.2	in	CCDA Lindbergh	10/18/1948	7:00	0.2
10	18	1948	8	0.05	in	CCDA Lindbergh	10/18/1948	8:00	0.05
10	18	1948	10	0.01	in	CCDA Lindbergh	10/18/1948	10:00	0.01
10	29	1948	4	0.09	in	CCDA Lindbergh	10/29/1948	4:00	0.09
10	29	1948	5	0.04	in	CCDA Lindbergh	10/29/1948	5:00	0.04
11	3	1948	22	0.03	in	CCDA Lindbergh	11/3/1948	22:00	0.03
11	3	1948	23	0.01	in	CCDA Lindbergh	11/3/1948	23:00	0.01
11	3	1948	24	0.01	in	CCDA Lindbergh	11/3/1948	24:00	0.01
11	4	1948	1	0.01	in	CCDA Lindbergh	11/4/1948	1:00	0.01
11	19	1948	24	0.01	in	CCDA Lindbergh	11/19/1948	24:00	0.01
11	26	1948	11	0.03	in	CCDA Lindbergh	11/26/1948	11:00	0.03

SCS SOIL TYPES A, B, C, and D for selecting hydro losses

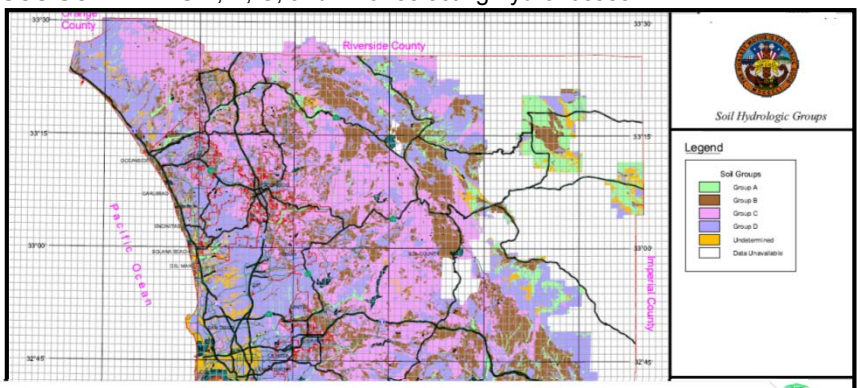


Table 4-4. INFILT Parameters

SCS Hydrologic Soil Group	INFILT Estimate (in/hr)	INFILT Estimate (mm/hr)	Runoff Potential
A	0.4 - 1.0	10.0 - 25.0	Low
B	0.1 - 0.4	2.5 - 10.0	Moderate
C	0.05 - 0.1	1.25 - 2.5	Moderate to High
D	0.01 - 0.05	0.25 - 1.25	High

Hydrologic Loss: (1) Horton's formula, (2) SCS CN, (3) Green-Ampt

References for City and County of San Diego, CA

Hydromodification Management Plan (HMP) AND **hourly rainfall data for San Diego**. HMP has description of our Peak Flow and Flow Duration performance criteria in Appendix E.
http://www.projectcleanwater.org/index.php?option=com_content&view=article&id=182&Itemid=188

San Diego BMP Sizing Calculator Methodology (Description of San Diego standard bioretention basin and flow-through planter on pages 1-13 and 1-17)
http://www.projectcleanwater.org/images/stories/Docs/LDS/SUSMP/SUSMP_SDBMP_Sizing_Calculator_Rpt_Jan2012.pdf

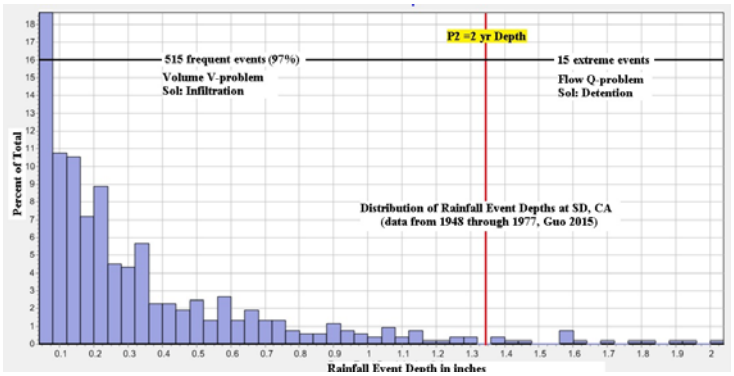
San Diego County Standard Urban Storm Water Mitigation Plan (land use "runoff factors" are on page 72 -basically anything impervious has runoff factor=1.0 and most pervious surfaces have runoff factor = 0.1)
http://www.sdcounty.ca.gov/dpw/watersheds/susmp/susmp.html

San Diego County Hydrology Manual (if we need this for NRCS runoff parameters or other info)
http://www.sdcounty.ca.gov/dpw/floodcontrol/hydrologymanual.html

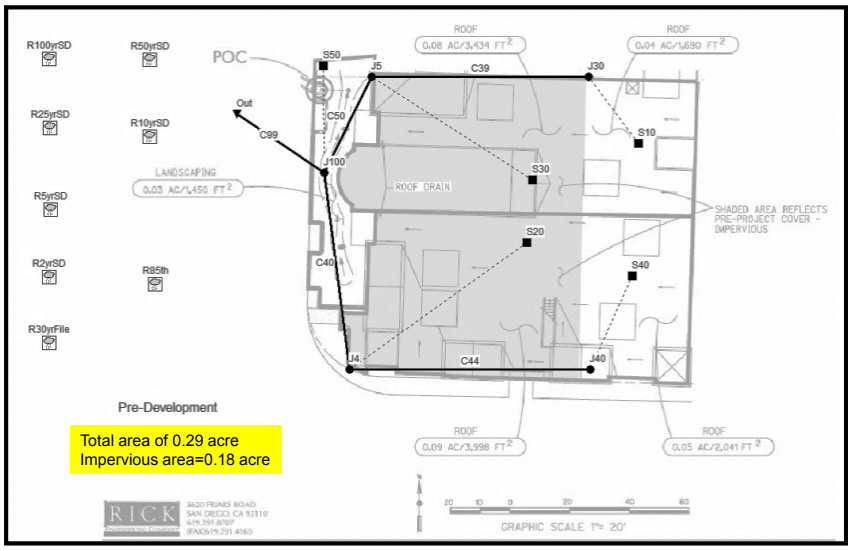
BASICS: Population of One-hr Precipitaiton Depths from 1948 to 1977 recorded at San Diego, CA

FACTS:
1. Only 15 events out of 30 years >2 yr event (i.e. 3%)
2. 97% of events<2 yr event

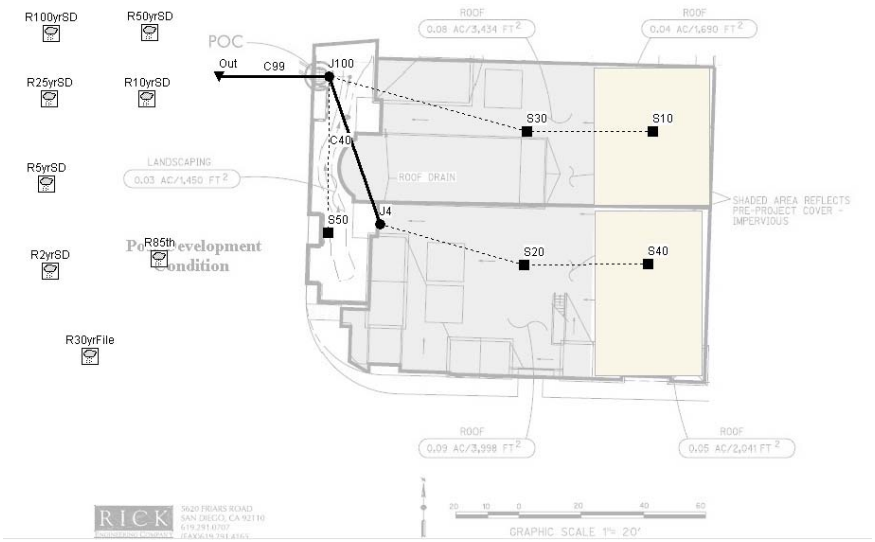
Two stormwater PROBLEMS from urbanization:
Q-problem (peak flow reduction for extreme events)
V-problem (runoff volume reduction for frequent events)



SWMM for Pre-development Condition



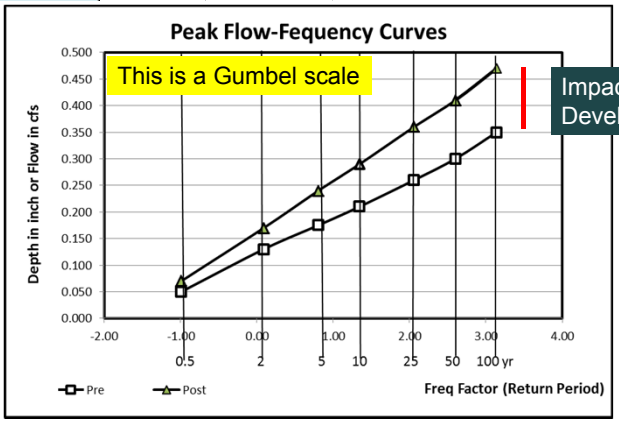
SWMM for Post-development Condition



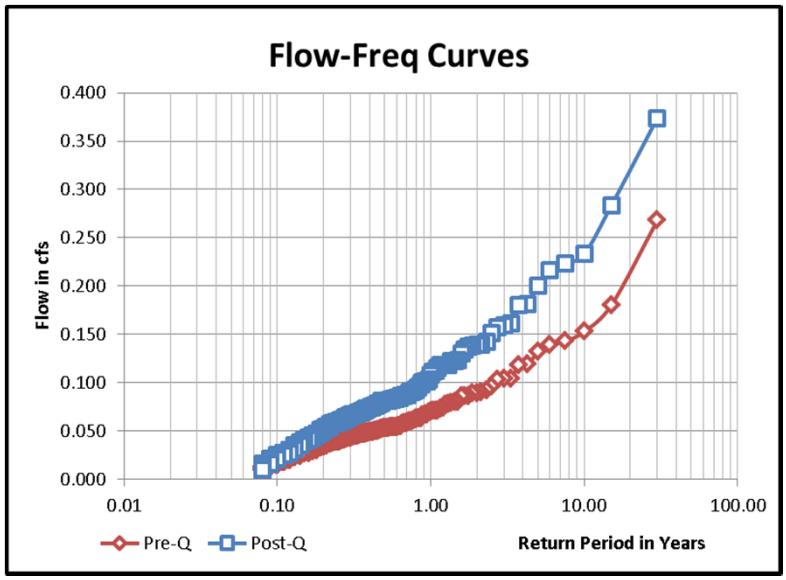
Return Period Tr year	P-24 Depth P-24 inch	Pre-Peak Flow Qp cfs	Post-Peak Flow Qp cfs
85th or 0.5	0.600	0.050	0.070
2.00	1.500	0.130	0.170
5.00	2.100	0.175	0.240
10.00	2.510	0.210	0.290
25.00	3.100	0.260	0.360
50.00	3.510	0.300	0.410
100.00	4.000	0.350	0.470

Q- Problem
Increase of Peak Flows

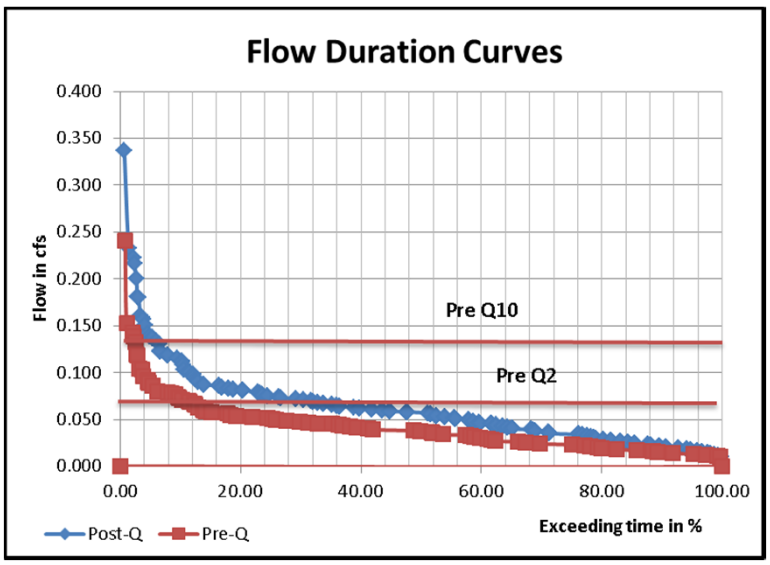
Solution: Flow Detention



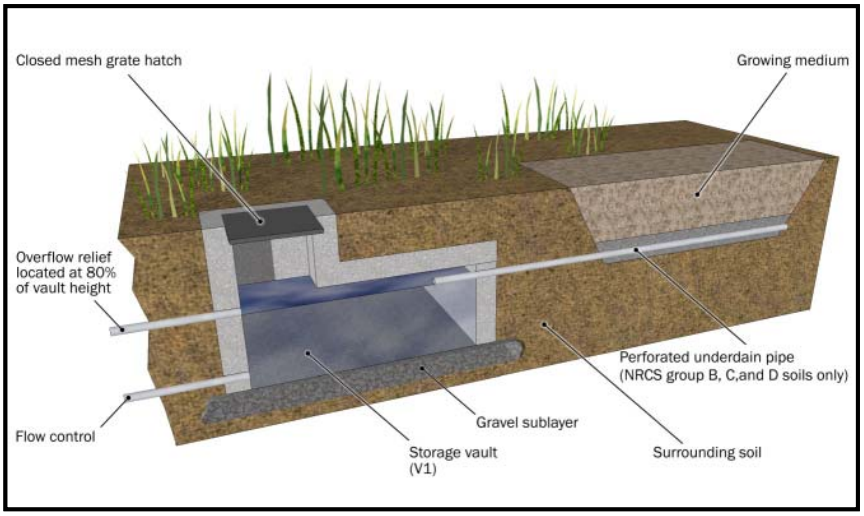
V-Problem = Increase of Runoff Volume (2015)
Solution: Infiltration Facilities such as LID Devices



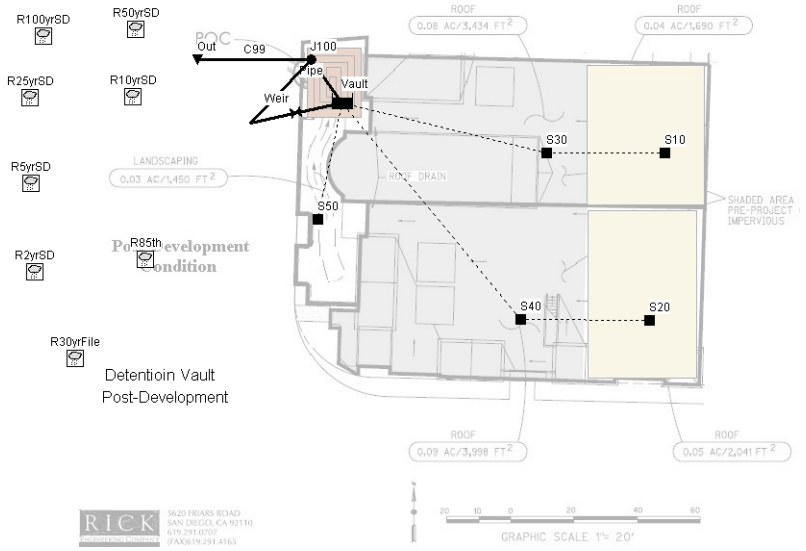
Pre- and Post flow-duration curves at project site (2015)
Problem related to **number of events**



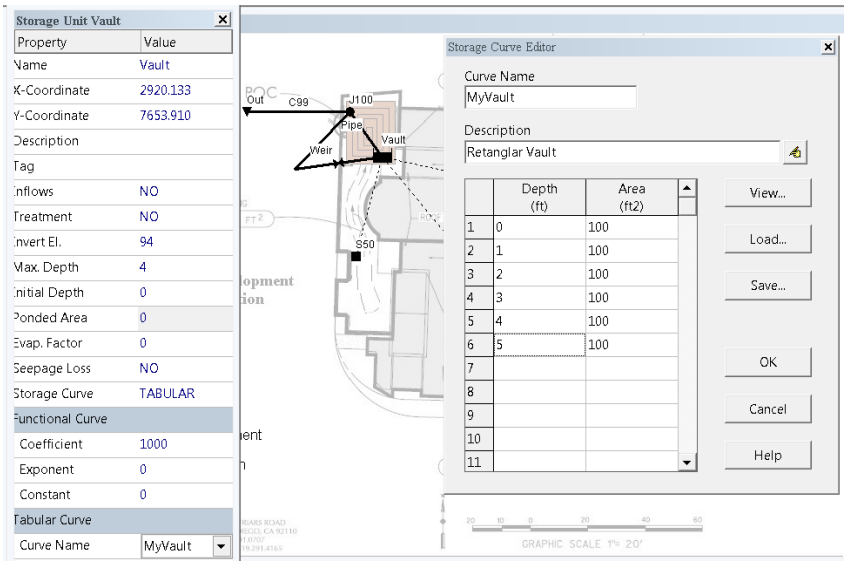
Underground Detention Vault for Flow Q Reduction



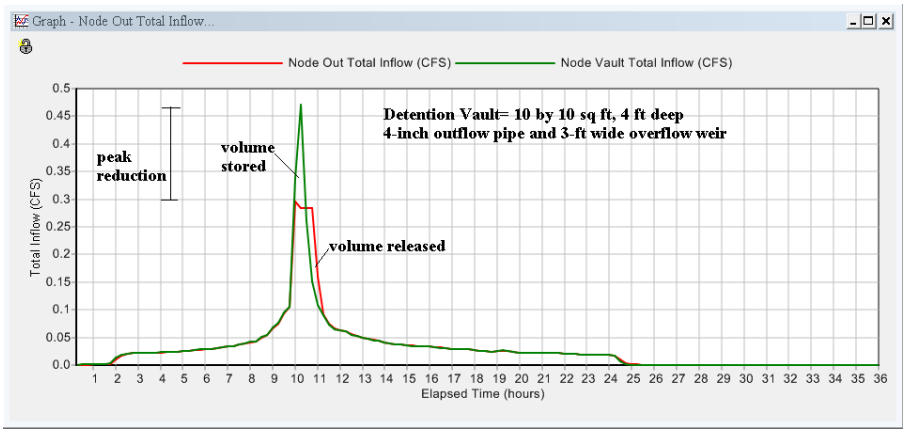
Model with Detention Vault



Flow Detention using Vault --- Flow Q Reduction



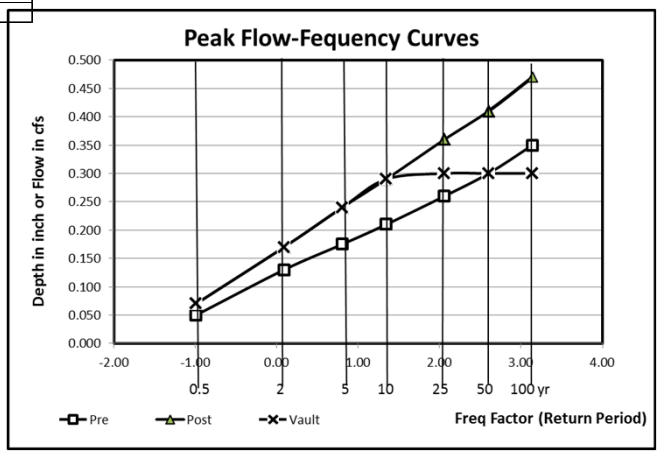
100-yr Peak Flow Reduction thru Detention Vault



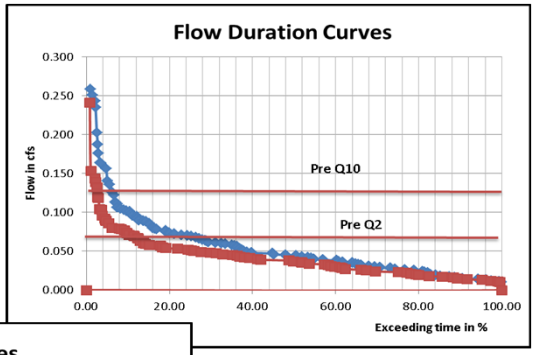
This is an approach to store water and then release it slowly. There is a process to reduce Q, but has NO Volume Reduction at all.

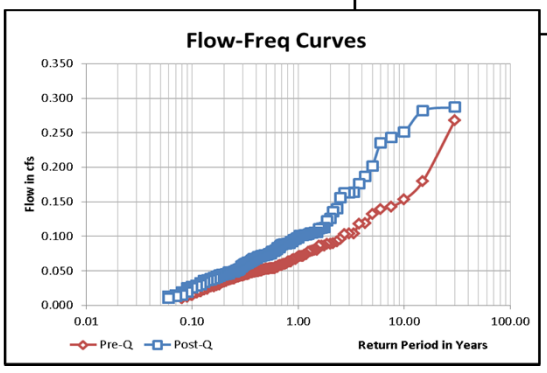
Return Period Tr year	P-24 Depth P-24 inch	Post-Peak Detention Vault cfs
85th or 0.5	0.60	0.07
2.00	1.50	0.17
5.00	2.10	0.24
10.00	2.51	0.29
25.00	3.10	0.3
50.00	3.51	0.3
100.00	4.00	0.3

Effectiveness of Detention Vault
1. Good Control of Events>Q10
2. No Control of Events<Q10
Why?



Underground Vault
Good Control for the 30-yr Event
No control for the rest





Discussions on Detention Vault for Q-Reduction

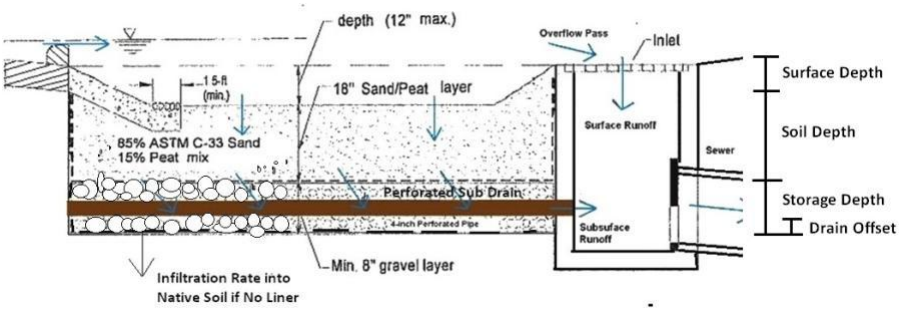
Hydrologic Aspect

1. How to size a vault?
2. Why would the vault only control flows>10-yr event?
3. How to improve its performance for a full-spectrum peak flow control?
4. If not, how to apply LID designs for a better flow control?
5. What is major differences in terms of runoff volume treatment between Vault and LIDs facilities?

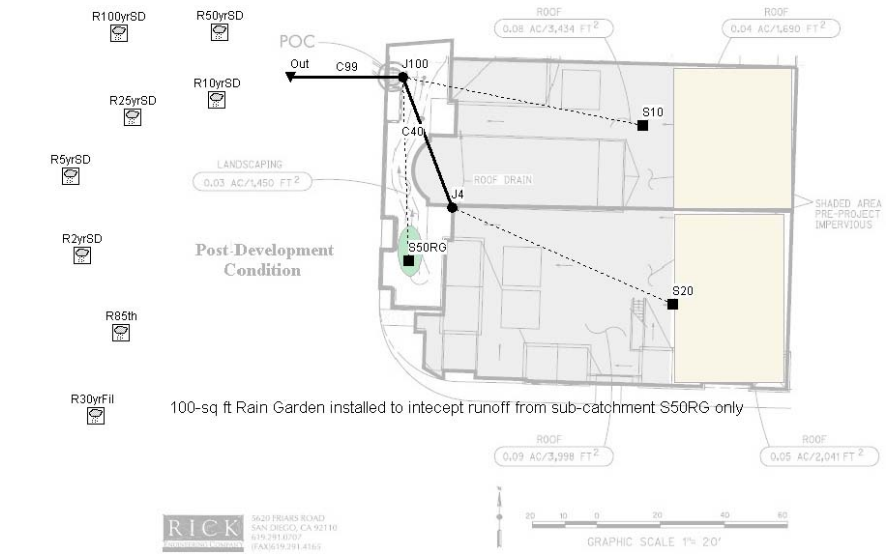
Hydraulic Aspect

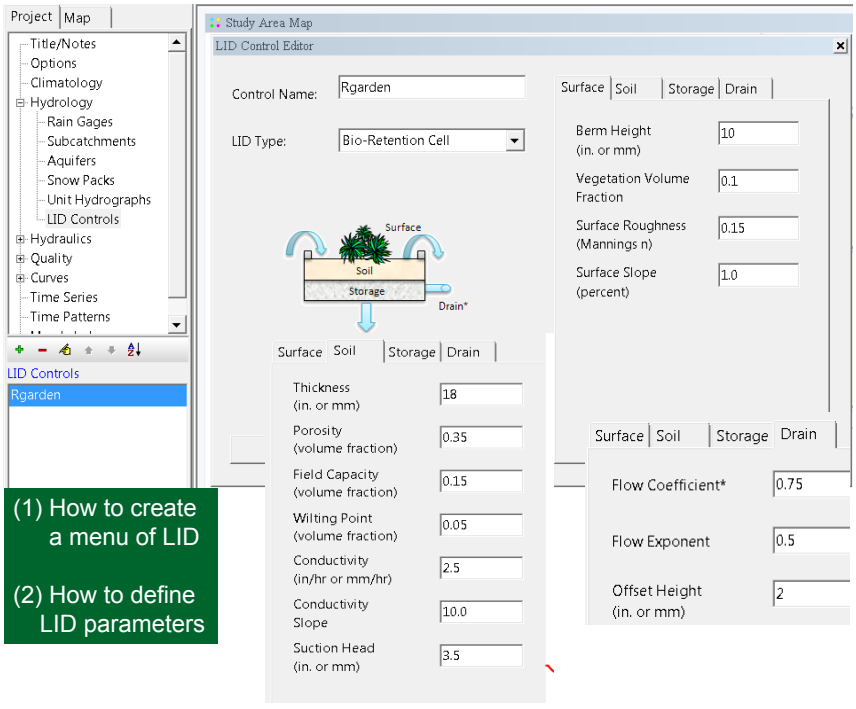
1. Considering hydraulic design, what is the major concern when having a vault of 4-ft underground?

Bio Retention Basin



Flow infiltration using a local rain garden – V Reduction





(1) How to create a menu of LID

(2) How to define LID parameters

Analysis of Flows through the Proposed Local Rain Garden

LOCAL Rain Garden LID

Watershed Information			
Tributary area	0.03	acre	PASTE PL
Impervious area	30.00	%	Start PL==>
Percent routed	100.00	%	
Rainfall depth	1.57	inch	
Imp area treated	0.01	acres	
Rain garden Information			
Water depth in basin	10.00	inch	
Basin surface area	300.00	sq.ft	Start PL==>
Basin to imp area ratio	22.96	%	
Sand layer			
Thickness	18.00	inch	
Porosity(100%saturation)	0.40		
Initial moisture	20.00	%	
Willing point (0%saturation)	0.10		
Eq initial mositure	0.16		
Gravel layer			
Thickness	30.00	inch	
Porosity(100%saturation)	0.43		
Initial moisture	20.00	%	
Willing point (0%saturation)	0.00		
Eq initial mositure	0.09		
Calcualtion of Infiltrating Flow			
Time step	15	min	
Inflow volume intercepted	0.01	ac-in	
Total inflow volume to basin	2.05	inch	
Initial storage volume	3.86	inch	
Bottom infiltration	24.24	inch	
Surface overflow	4.10	inch	
Drain outflow	29.16	inch	
Surface infiltration	24.24	inch	
Soil percolation	50.50	inch	
Final storage	21.33	inch	

SWMM REPORT

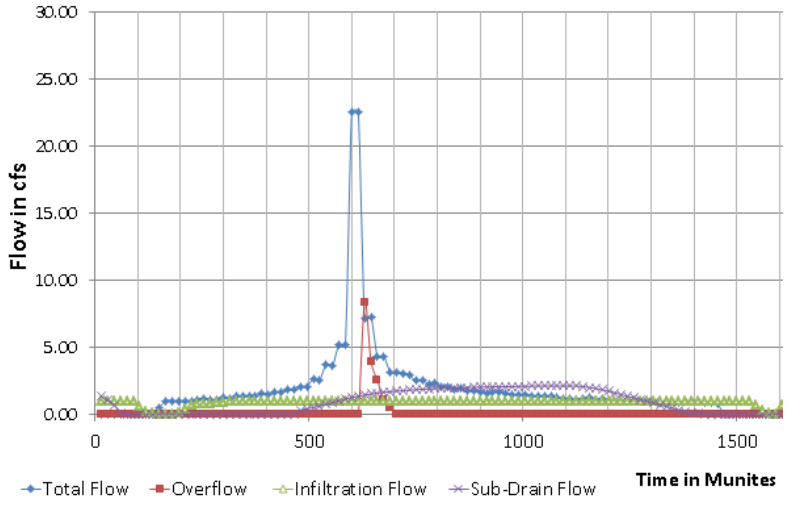
Subcatchmer	LID	Total inflow (in)	Evap. Loss (in)	Infil. Loss (in)	Surface outflow (in)	Drain outflow (in)	Initial storgae (in)	Final storage (in)	Error	Bottom Infil (in)	Soil Perc (in)
S50RG	Rgarden	50.93	0	23.94	4.1	25.05	3.65	1.8	-0.57		
Calculator	Total	203.73	0.00	96.96	16.41	116.64				96.96	202.00
15	Vol (inch)	50.93	0.00	24.24	4.10	29.16	3.66	21.33		24.24	50.50

SWMM5 LID Report File

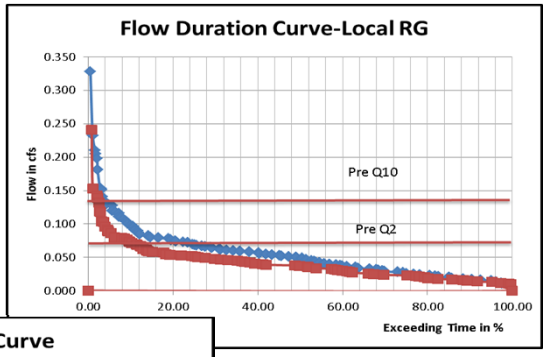
Project:
LID Unit: Rgarden in Subcatchment S50RG

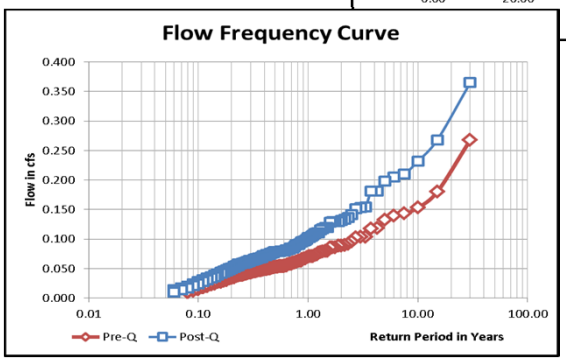
Elapsed Time Hours	Total Inflow in/hr	Total Evap in/hr	Surface Infil in/hr	Soil Perc in/hr	Bottom Infil in/hr	Surface Runoff in/hr	Drain Outflow in/hr	Surface Depth inches	Soil/ Pave Moist	Storage Depth inches
0.25	0	0	0	0	1	0	1.37	0	0.16	5.31
0.5	0.04	0	0.04	0	1	0	1.07	0	0.16	4.02
0.75	0.04	0	0.04	0	1	0	0.72	0	0.16	2.91
1	0.05	0	0.05	0	1	0	0.1	0	0.16	2.09
1.25	0.04	0	0.04	0	1	0	0	0	0.16	1.48
1.5	0.05	0	0.05	0	1	0	0	0	0.16	0.89
1.75	0.05	0	0.05	0	0.65	0	0	0	0.16	0.41
2	0.04	0	0.04	0	0.28	0	0	0	0.16	0.14
2.25	0.05	0	0.05	0	0.1	0	0	0	0.16	0.03
2.5	0.54	0	0.54	0	0	0	0	0	0.17	0
2.75	1.05	0	1.05	0	0	0	0	0	0.18	0
3	1.06	0	1.06	0	0	0	0	0	0.19	0
3.25	1.05	0	1.05	0.43	0.18	0	0	0	0.21	0.07
3.5	1.05	0	1.05	0.78	0.4	0	0	0	0.21	0.25
3.75	1.06	0	1.06	0.79	0.71	0	0	0	0.22	0.39
4	1.14	0	1.14	0.83	0.77	0	0	0	0.22	0.43
4.25	1.22	0	1.22	0.87	0.81	0	0	0	0.22	0.46
4.5	1.14	0	1.14	0.9	0.86	0	0	0	0.23	0.49
4.75	1.14	0	1.14	0.93	0.9	0	0	0	0.23	0.52
5	1.3	0	1.3	0.97	0.92	0	0	0	0.24	0.54
5.25	1.22	0	1.22	1	0.97	0	0	0	0.24	0.56
5.5	1.38	0	1.38	1.04	1	0	0	0	0.24	0.59
5.75	1.37	0	1.37	1.09	1	0	0	0	0.25	0.63
6	1.38	0	1.38	1.13	1	0	0	0	0.25	0.69
6.25	1.38	0	1.38	1.17	1	0	0	0	0.25	0.78
6.5	1.62	0	1.62	1.22	1	0	0	0	0.26	0.89
6.75	1.54	0	1.54	1.28	1	0	0	0	0.26	1.03
7	1.7	0	1.7	1.34	1	0	0	0	0.27	1.21
7.25	1.7	0	1.7	1.4	1	0	0	0	0.27	1.43
7.5	1.87	0	1.87	1.47	1	0	0	0	0.28	1.68
7.75	1.86	0	1.86	1.55	1	0	0	0	0.28	1.98
8	2.11	0	2.11	1.62	1	0	0.34	0	0.29	2.22
8.25	2.11	0	2.11	1.74	1	0	0.46	0	0.29	2.38
8.5	2.68	0	2.68	1.89	1	0	0.55	0	0.3	2.56
8.75	2.6	0	2.6	2.08	1	0	0.65	0	0.31	2.79

Flow Analyses Through A Rain Garden



Local Rain Garden

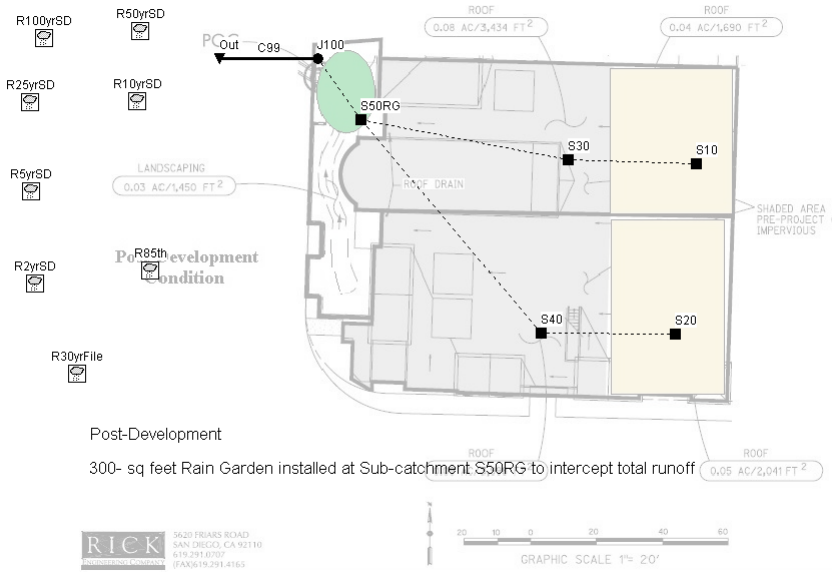




Discussions on LOCAL Rain Garden Design

1. How to size a rain garden?
2. Can you revise the model to apply SD's criteria?
3. How to confirm if a rain garden is sufficient?
4. How to convert a local RG into a watershed-wide RG?
5. Pros and Cons between local and watershed-wide RG.
6. How to trace the runoff amount intercepted by the RG?
7. How to trace overtopping flows after the RG became full?
8. Can you tell how the inflow was divided into infiltrating, overtopping, and storage flows through the RG?
9. Define surface infiltrating, mid percolating, and bottom infiltrating flows through a soil column.

300-sq ft Rain Garden for the Entire Watershed

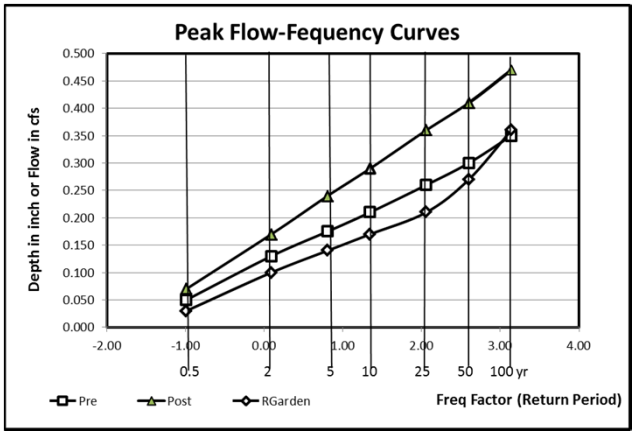


Post-Development

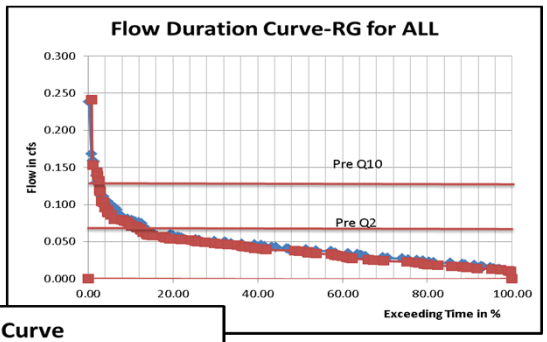
300- sq feet Rain Garden installed at Sub-catchment S50RG to intercept total runoff

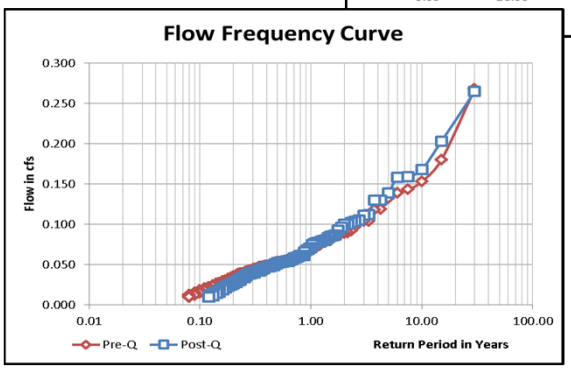
Return Period Tr year	P-24 Depth P-24 inch	Post-Peak Rain Garden cfs
85th or 0.5	0.60	0.03
2.00	1.50	0.1
5.00	2.10	0.14
10.00	2.51	0.17
25.00	3.10	0.21
50.00	3.51	0.27
100.00	4.00	0.36

Effectiveness of 300-sq feet Rain Garden
Not a Good Control for Events<Q10
Good Control for Events>Q50



300-sq ft Rain Garden

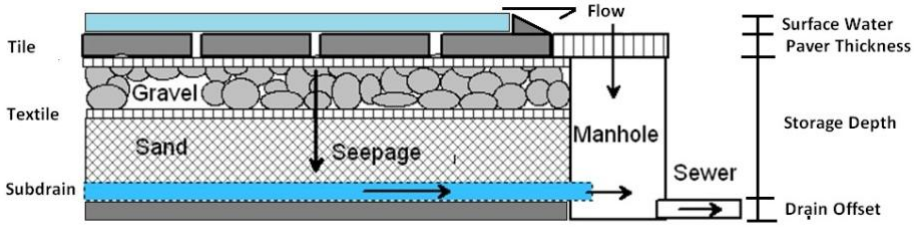




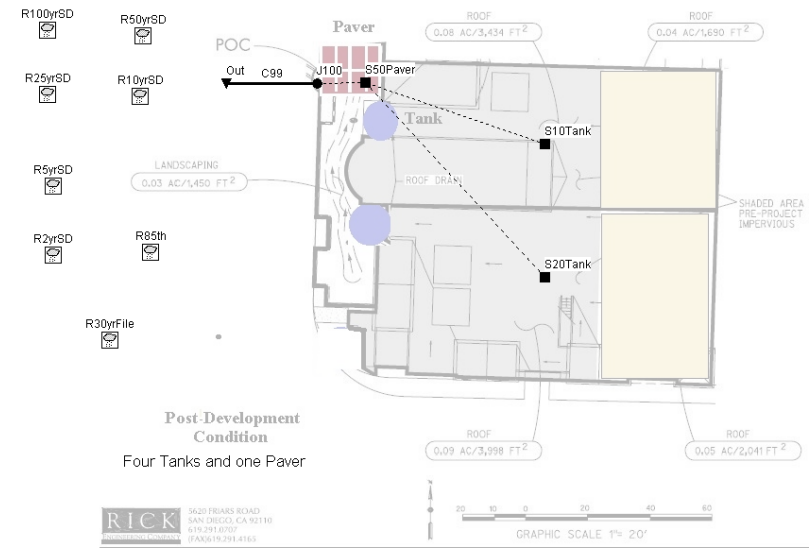
Discussions on Rain Garden Design

1. How to size a watershed-wide rain garden?
2. Can you revise the model to apply SD's criteria?
3. Explain why the infiltrating rate through the filtering medium under the rain garden can be as high as 5.0 in/hr while the infiltrating rate on native soils is reduced to 0.5 inch/hr?
4. Do we need a gravel layer of 30 inches? If so, why?
5. Change the infiltration parameters to see if the rain garden will perform differently? If not, why?
6. How does SWMM treat the deficit of soil antecedent moisture?
7. Shall we also consider unsaturated soil conductivity?
8. What will you do differently if the rain garden is located in a cold zone?

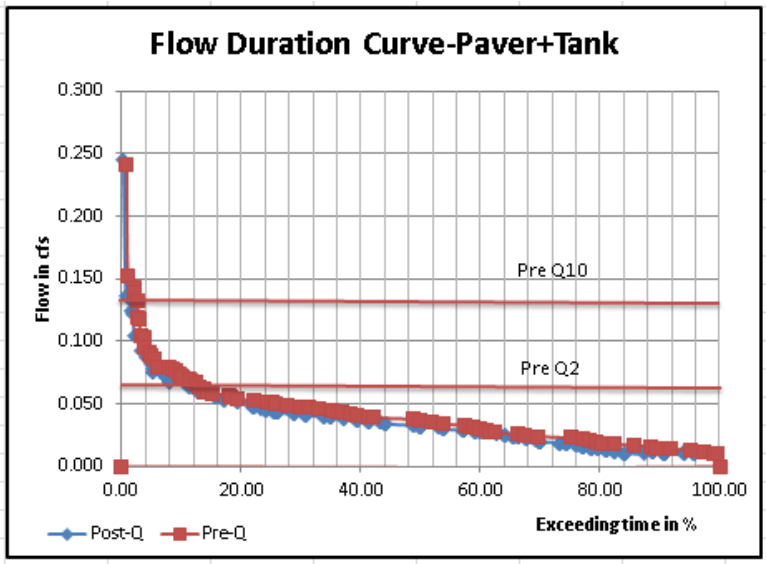
Porous Pavers for Stormwater Disposal --- Source Control



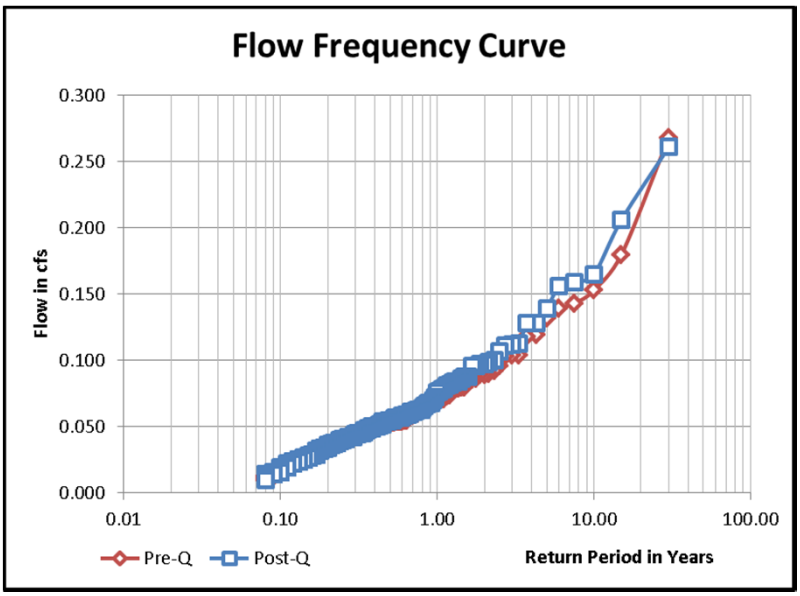
900-sq ft Paver and Rain Tanks



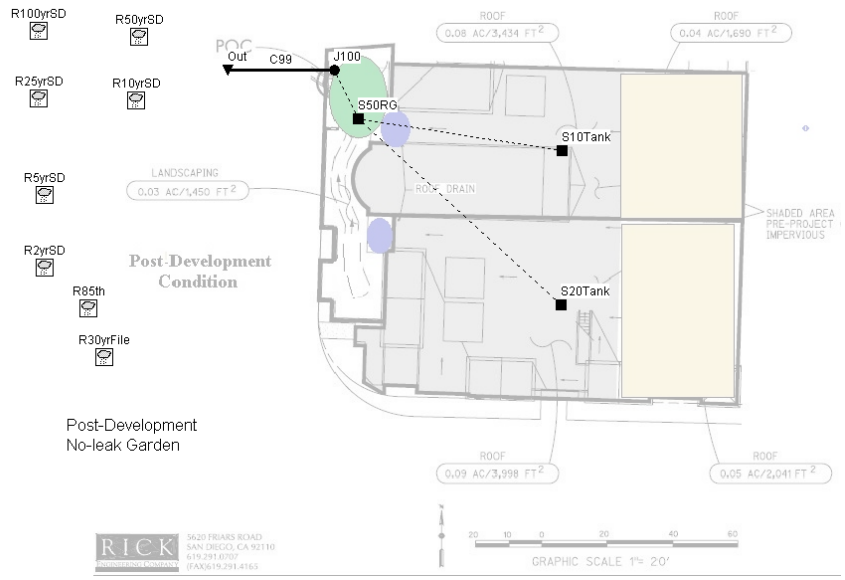
Flow Duration Curves for 900-sq ft Paver and Tanks



Flow Frequency Curves with 900-sq ft Paver and Tanks

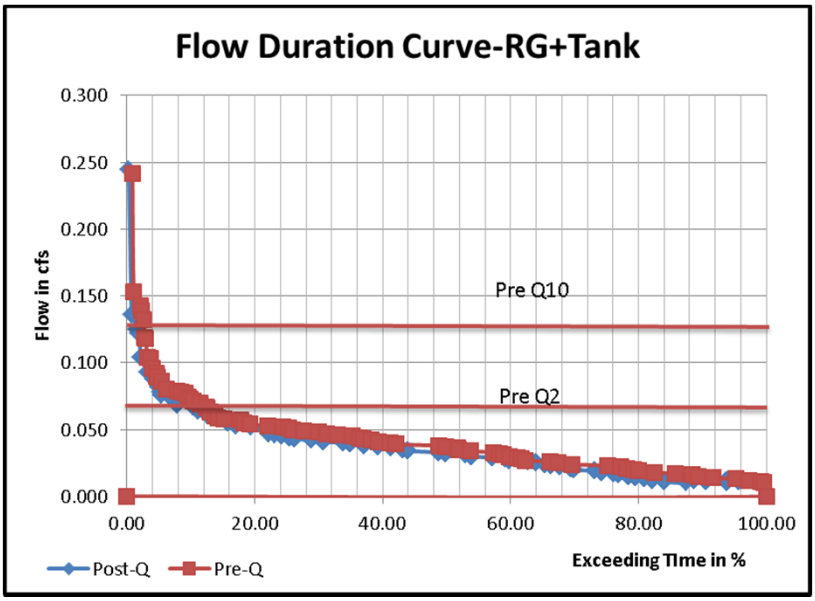


300-sq ft Rain Garden and 2 Tanks

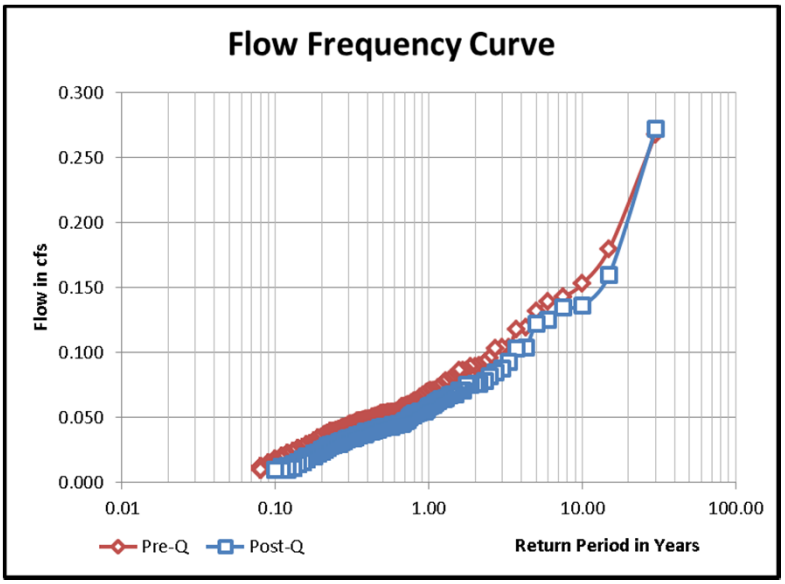


Post-Development
No-leak Garden

Flow Duration Curves for 300-sq ft Rain Gardens and 2 Tanks



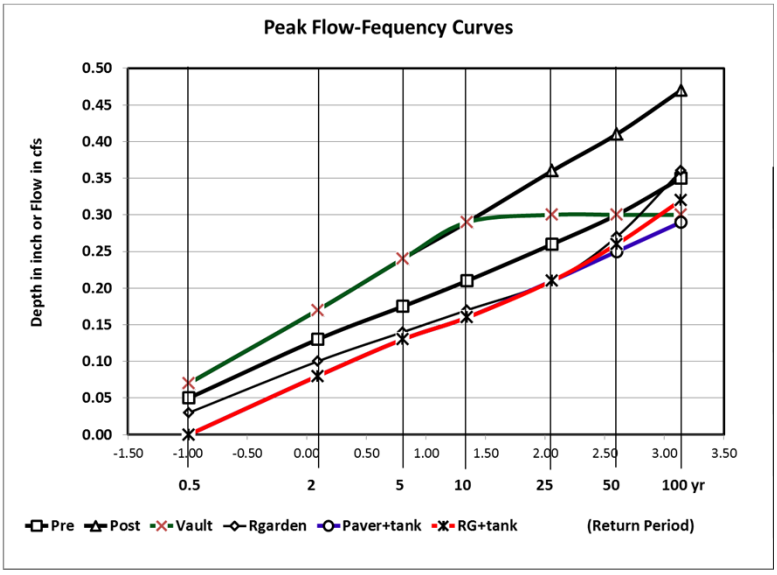
Flow Frequency Curves with 300-sq ft Rain Garden + 2 Tanks



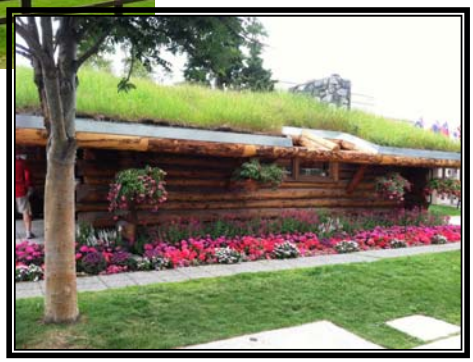
Discussions on Cistern and Bio-Retention Design

1. How to size a rain tank (cistern) according to SD criteria?
2. How to add a cistern to each roof area, i.e. two cisterns for old roof areas, so are for new roof areas.
3. Can you revise the model to have (1) and (2)?
4. Can SWMM model a cistern with a bio-retention for WQ control? If so, how?
5. Exam the effectiveness of these rain tanks for Q2?
6. Show the diminishing effect for Q100.

Flow Frequency Curves with Various Alternatives



Discussions:
How green is green enough?



To get more Info from Dr. James C.Y. Guo

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WWW.UCDENVER.EDU/~Jguo -- Website
WWW.UDFCD.ORG -- Free Software
WWW.URBANWATERSHEDS.ORG – Training Classes

Porous Pavements in UC-Denver Campus