University of Central Florida Stormwater Management Academy "Managed Stormwater is Good Water"

9th Biennial Conference on Stormwater Research and Watershed Management

Department of Environmental Protection Florida

Green Roof Stormwater Treatment System Cistern Design in Florida

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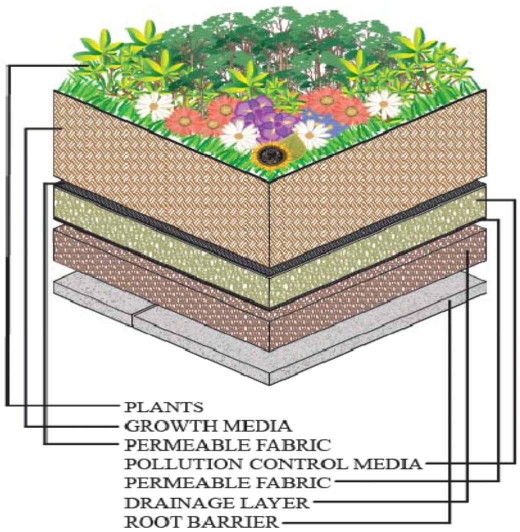
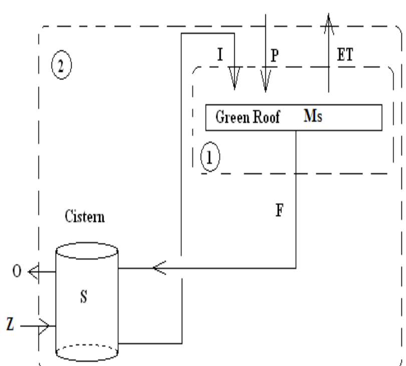
Why Use Green Roof Stormwater Treatment Systems

- Aesthetically Pleasing
- Enhance Biodiversity
- Increase Energy Efficiency
- Increase Roof Life
- Reduce Urban Heat Island Effect
- Increase Pervious Area (Post = Pre)
- Ability to Treat Additional Impervious Areas

Green Roof Design

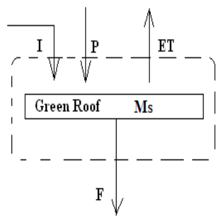


Variable Identification



- Mass Balance
  - Precipitation
  - Irrigation
  - Media Storage
  - Cistern Storage
  - Evapotranspiration
  - Filtrate or filtrate factor
    - F' = f*(P' + I')
  - Overflow
  - Makeup Water

Experimental Results



- Interested in ET and f
  - F’ = f*(P’ + I’)
- Mass Balance:
  $dM_S/dt = P + I – ET – F$
- Assuming Finite Time Step:
  $\Delta M_S/\Delta t = P + I – ET – F$
  $\Delta M_S = \Delta t*(P + I – ET – F)$
  $\Delta M_S = P' + I' – ET' – F'$
  - Where Prime is Indicative of Volume

Experimental Results (Cont.)

- ET and Media Storage Cannot be Measured Directly
  - The Change in Media Storage can be Approximated as 0
- ET can now be Solved for
  - ET’ = P’ + I’ – F’
- f can be calculated
  - f = F’/(P’ + I’)

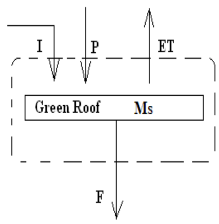
Experimental Results (Cont.)

ET Monthly Average Comparison of the Chambers [in/day]									
Date	TVO1	TVR1	TO1	TR1	C1	EVO1	EVR1	EO1	ER1
Jul-05	**0.26**	0.24	0.22	0.14	0.02	0.17	0.17	0.14	0.14
Aug-05	0.20	0.17	0.17	0.16	0.00	0.14	0.14	0.15	0.14
Sep-05	0.18	0.16	0.14	0.12	0.00	0.17	0.14	0.10	0.09
Oct-05	0.11	0.10	0.09	0.09	0.00	0.11	0.10	0.07	0.07
Nov-05	0.10	0.08	0.09	0.07	0.00	0.11	0.09	0.07	0.08
Dec-05	0.09	0.08	0.09	**0.07**	0.00	0.09	0.08	0.08	0.07
Jan-06	0.10	0.08	0.09	0.09	0.00	0.11	0.09	0.08	0.08
Feb-06	0.11	0.08	0.11	0.09	0.00	0.12	0.10	0.09	0.09
Mar-06	0.13	0.12	0.15	0.11	0.00	0.14	0.12	0.11	0.11
Apr-06	0.17	0.13	0.16	0.13	0.00	0.17	0.15	0.12	0.12
May-06	0.16	0.14	0.13	0.11	0.00	0.16	0.13	0.11	0.10
Jun-06	0.20	0.18	0.17	0.16	0.00	0.17	0.17	0.16	0.14

Experimental Results (Cont.)

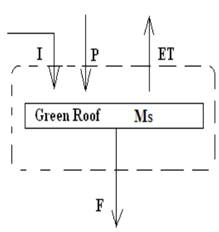
f Factor Monthly Average Comparison of the Chambers									
Date	TVO1	TVR1	TO1	TR1	C1	EVO1	EVR1	EO1	ER1
Jul-05	0.54	0.42	0.61	0.50	0.96	0.64	0.52	0.70	0.50
Aug-05	0.46	0.24	0.52	0.35	0.94	0.62	0.39	0.67	0.39
Sep-05	0.58	0.44	0.69	0.50	0.98	0.63	0.52	0.70	0.56
Oct-05	0.71	0.60	0.75	0.60	0.97	0.71	0.55	0.81	0.67
Nov-05	0.67	0.46	0.70	0.49	0.94	0.62	0.40	0.76	0.51
Dec-05	0.74	0.59	0.74	0.61	0.98	0.73	0.58	0.77	0.61
Jan-06	0.70	0.49	0.72	0.47	0.86	0.65	0.45	0.75	0.52
Feb-06	0.65	0.51	0.68	0.46	0.98	0.62	0.45	0.72	0.48
Mar-06	0.54	0.19	0.49	0.24	-	0.54	0.19	0.62	0.25
Apr-06	0.47	0.25	0.50	0.26	0.97	0.49	0.14	0.62	0.28
May-06	0.50	0.26	0.58	0.37	0.99	0.52	0.27	0.66	0.41
Jun-06	0.56	0.42	0.62	0.48	0.99	0.62	0.44	0.65	0.55

Experimental Results (Example Calculation, No Cistern)



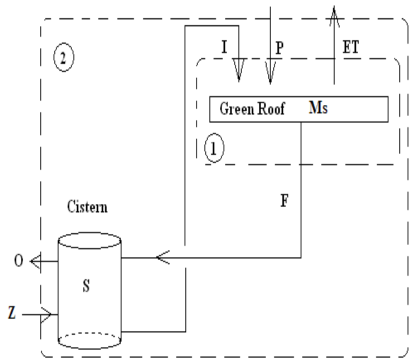
- Mass Balance for EVR1
- $dM_S/dt = P + I – ET – F$
- $\Delta M_S/\Delta t = P + I – ET – F$
- $\Delta M_S = \Delta t*(P + I – ET – F)$
- $\Delta M_S = P' + I' – ET' – F'$
- As Δt gets Large $\Delta M_S = 0$

Experimental Results (Example Calculation, No Cistern)



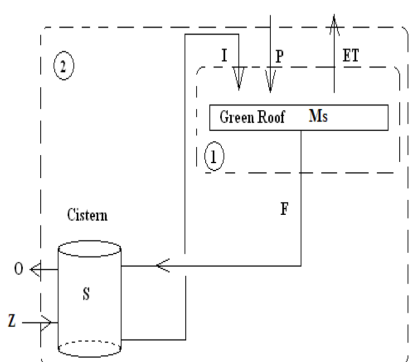
- Mass Balance for EVR1 Cont.
  - 1 Year Period
  - P' = 44.3 inches
  - I' = 48.4 inches
  - ET' = 44.6 inches
  - F' = 48.2 inches
- Note: More filtrate than rainfall due to irrigation

Experimental Results (Example Calculation, With Cistern)



- Mass Balance for EVR1 System
- $d(S + M_S)/dt = P + Z – O – ET$
- $\Delta(S + M_S)/\Delta t = P + Z – O – ET$
- $\Delta(S + M_S) = \Delta t*(P + Z – O – ET)$
- $\Delta(S + M_S) = P' + Z' – O' – ET'$
- For Large Time Step
  - $\Delta(S + M_S) = 0$

Experimental Results (Example Calculation, With Cistern)

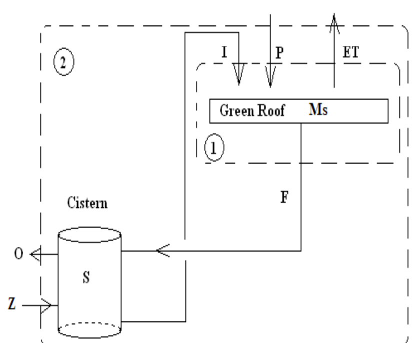


- Mass Balance for EVR1 System Cont.
  - 1 Year Period
  - P' = 44.3 inches
  - Z' = 11.02 inches
  - ET' = 44.6 inches
  - O' = 7.5 inches
- Efficiency = 83%
  - $Eff = [1 – (\Sigma O'/ \Sigma P')]$
  - Note: without cistern overflow/filtrate was 48.2 inches

Model Development

- Developed Based on a Mass Balance
  - Determines Cistern Response to P and I on a Green Roof
  - Dynamically Solves for f for each Event
  - Determines System Efficiency Based on Historical and Measured Data

Model Development

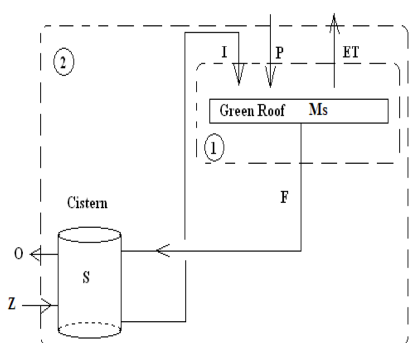


- First Take System Boundaries for 1
- Solve for the f Factor and Develop Eqn's to Describe Media Storage

Model Development

- $\Delta M_S = P' + I' - ET' - F'$
- $\Delta M_S = P' + I' - ET' - f^*(P' + I')$
- $f = (\Delta M_S + P' + I' - ET')/(P' + I')$ [1]
- $M_{S2} = M_{sat} - ET'$ or [2]
- $M_{S2} = M_{S1} + P' + I' - ET'$ [3]
- These Equations are Solved at Each Time Step

Model Development

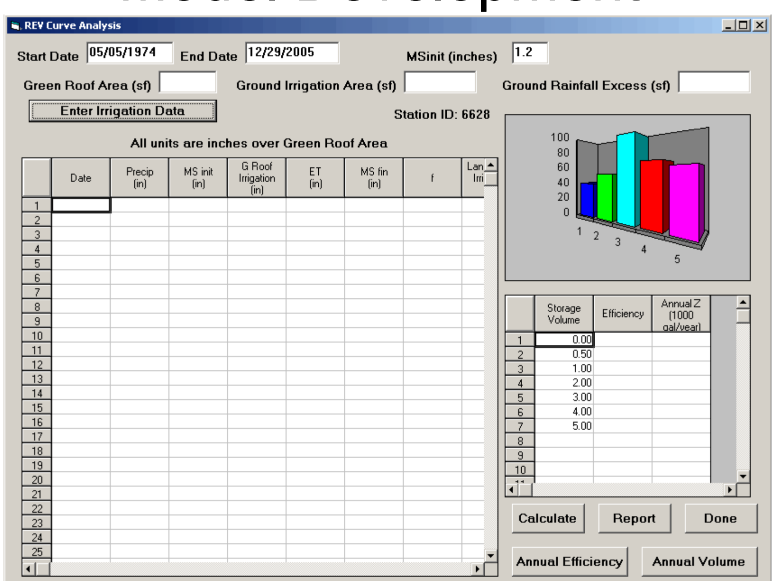


- Next Take System Boundaries Around the Cistern
- Develop Eqn's to Describe Cistern Behavior

Model Development

- $dS/dt = F + Z – O – ET$
- $\Delta S/\Delta t = F + Z – O – ET$
- $\Delta S = \Delta t*(F + Z – O – ET)$
- $S1 + f(P' + I') + Z' – I' – O' = S2$ [4]
- This Equation is Solved at Each Time Step Simultaneously with Eqn 1
- Efficiency Calc = $[1 – (\Sigma O'/ \Sigma P')]$

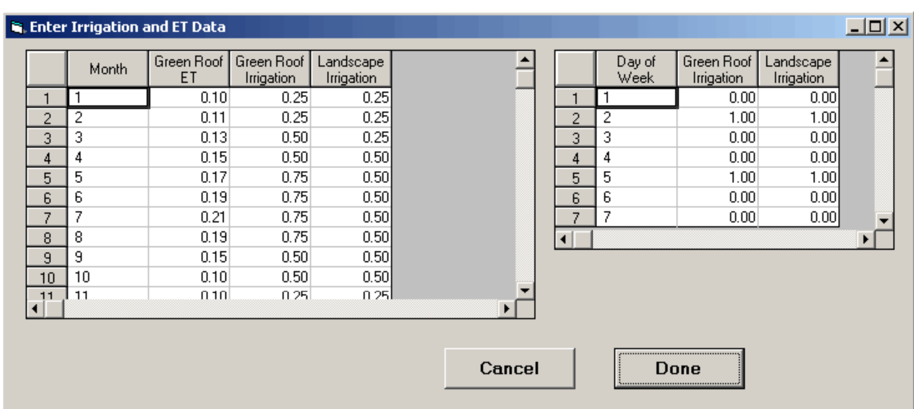
Model Development



Model Development

- This Model Allows the User to Modify the Following Variables
  - Irrigation Rate
  - ET Rate
  - Precipitation Data
    - All Factors Vary Regionally
- This Model Can also Incorporate
  - Additional Impervious Areas as an Input
  - Additional Pervious Areas as an Output

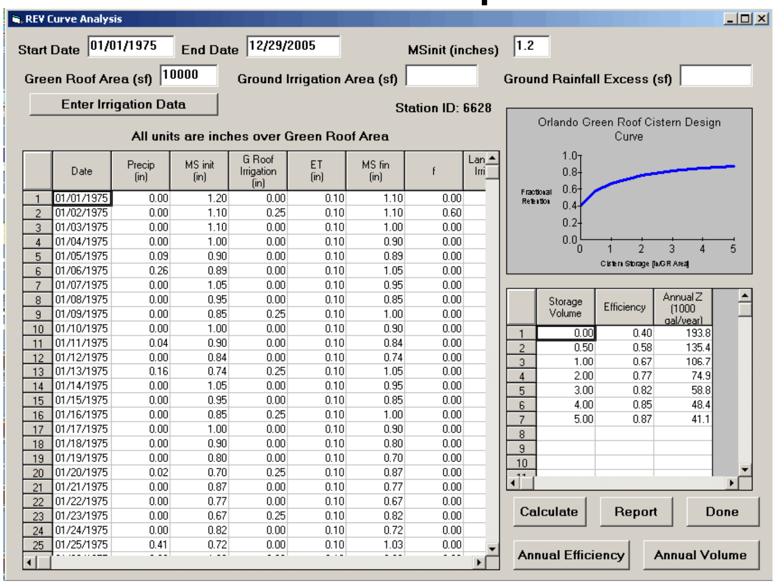
Model Development



	Month	Green Roof ET	Green Roof Irrigation	Landscape Irrigation
1	1	0.10	0.25	0.25
2	2	0.11	0.25	0.25
3	3	0.13	0.50	0.25
4	4	0.15	0.50	0.50
5	5	0.17	0.75	0.50
6	6	0.19	0.75	0.50
7	7	0.21	0.75	0.50
8	8	0.19	0.75	0.50
9	9	0.15	0.50	0.50
10	10	0.10	0.50	0.50
11	11	0.10	0.25	0.25

	Day of Week	Green Roof Irrigation	Landscape Irrigation
1	1	0.00	0.00
2	2	1.00	1.00
3	3	0.00	0.00
4	4	0.00	0.00
5	5	1.00	1.00
6	6	0.00	0.00
7	7	0.00	0.00

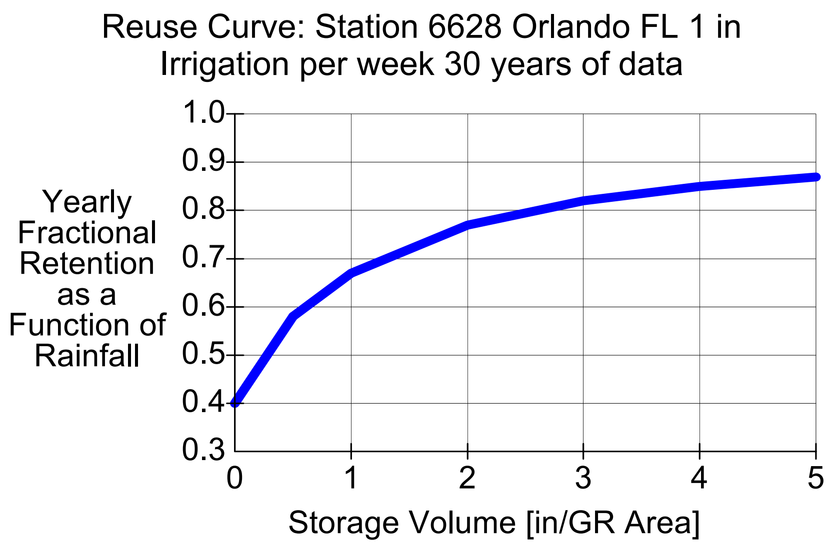
Model Development



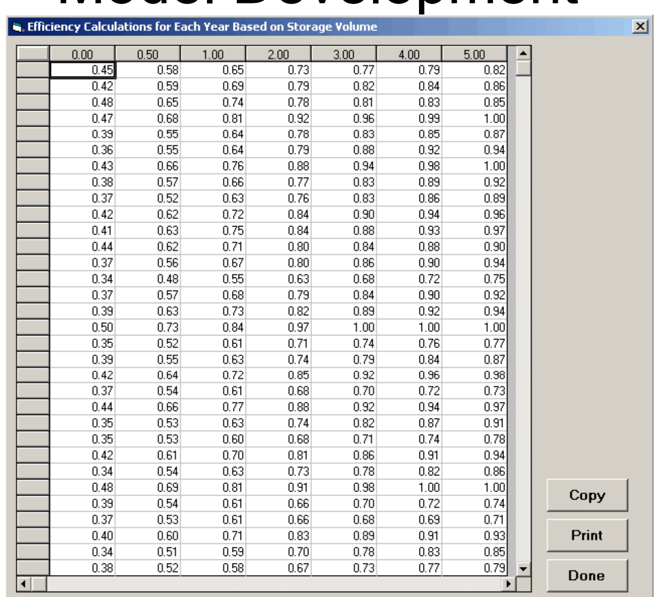
Model Development

- Model allows for the calculation of average efficiency over entire time period and yearly efficiency
  - Also for average makeup water required and yearly makeup water required
- This allows user to see how yearly precipitation volume effects both efficiency and makeup water requirements

Model Development



Model Development



0.00	0.50	1.00	2.00	3.00	4.00	5.00
0.45	0.58	0.65	0.73	0.77	0.79	0.82
0.42	0.59	0.69	0.79	0.82	0.84	0.86
0.48	0.65	0.74	0.78	0.81	0.83	0.85
0.47	0.68	0.81	0.92	0.96	0.99	1.00
0.39	0.55	0.64	0.78	0.83	0.85	0.87
0.36	0.55	0.64	0.79	0.88	0.92	0.94
0.43	0.66	0.76	0.88	0.94	0.98	1.00
0.38	0.57	0.66	0.77	0.83	0.89	0.92
0.37	0.52	0.63	0.76	0.83	0.86	0.89
0.42	0.62	0.72	0.84	0.90	0.94	0.96
0.41	0.63	0.75	0.84	0.88	0.93	0.97
0.44	0.62	0.71	0.80	0.84	0.88	0.90
0.37	0.56	0.67	0.80	0.86	0.90	0.94
0.34	0.48	0.55	0.63	0.68	0.72	0.75
0.37	0.57	0.68	0.79	0.84	0.90	0.92
0.39	0.63	0.73	0.82	0.89	0.92	0.94
0.50	0.73	0.84	0.97	1.00	1.00	1.00
0.35	0.52	0.61	0.71	0.74	0.76	0.77
0.39	0.55	0.63	0.74	0.79	0.84	0.87
0.42	0.64	0.72	0.85	0.92	0.96	0.98
0.37	0.54	0.61	0.68	0.70	0.72	0.73
0.44	0.66	0.77	0.88	0.92	0.94	0.97
0.35	0.53	0.63	0.74	0.82	0.87	0.91
0.35	0.53	0.60	0.68	0.71	0.74	0.78
0.42	0.61	0.70	0.81	0.86	0.91	0.94
0.34	0.54	0.63	0.73	0.78	0.82	0.86
0.48	0.69	0.81	0.91	0.98	1.00	1.00
0.39	0.54	0.61	0.66	0.70	0.72	0.74
0.37	0.53	0.61	0.66	0.68	0.69	0.71
0.40	0.60	0.71	0.83	0.89	0.91	0.93
0.34	0.51	0.59	0.70	0.78	0.83	0.85
0.38	0.52	0.58	0.67	0.73	0.77	0.79

Model Development

(Fraction Retention as a Function of Cistern Volume)

* no irrigation at zero cistern volume

	Cistern Storage Volume [in/GR Area]					
Location	0*	1	2	3	4	5
Belle Glade	0.5	0.72	0.8	0.84	0.87	0.89
Boca Raton	0.42	0.61	0.69	0.73	0.77	0.79
Brooksville	0.45	0.66	0.74	0.78	0.81	0.83
Daytona Beach	0.42	0.66	0.74	0.79	0.82	0.85
Ft. Myers	0.44	0.65	0.72	0.76	0.79	0.81
Gainesville	0.42	0.67	0.76	0.8	0.83	0.86
Homestead	0.44	0.64	0.71	0.75	0.77	0.79
Jacksonville	0.4	0.65	0.73	0.77	0.8	0.82
Key West	0.51	0.72	0.8	0.85	0.88	**0.9**
Lakeland	0.42	0.67	0.75	0.8	0.83	0.85
Miami	0.42	0.63	0.69	0.73	0.76	0.78
Niceville	**0.33**	0.57	0.65	0.69	0.71	0.73
Orlando	0.40	0.67	0.78	0.82	0.85	0.87
Panama City	**0.33**	0.57	0.66	0.7	0.73	0.76
Tallahassee	**0.35**	0.58	0.66	0.7	0.72	0.74
Tampa	0.44	0.69	0.77	0.82	0.84	0.86
Venice	0.47	0.7	0.78	0.83	0.86	0.88
West Palm	0.42	0.62	0.69	0.73	0.76	0.78

Example Problem

- Design an 800 square foot green roof to be located on the new stormwater lab addition at the University of Central Florida. The roof drains via an interior drain system routed to a cistern for storage and irrigation. The desired yearly hydrologic efficiency of the system is 80%. The green roof is to be a passive roof and consist of a water proof membrane, drainage layer, 2 inches of pollution control media, 4 inches of growing media, and vegetation.

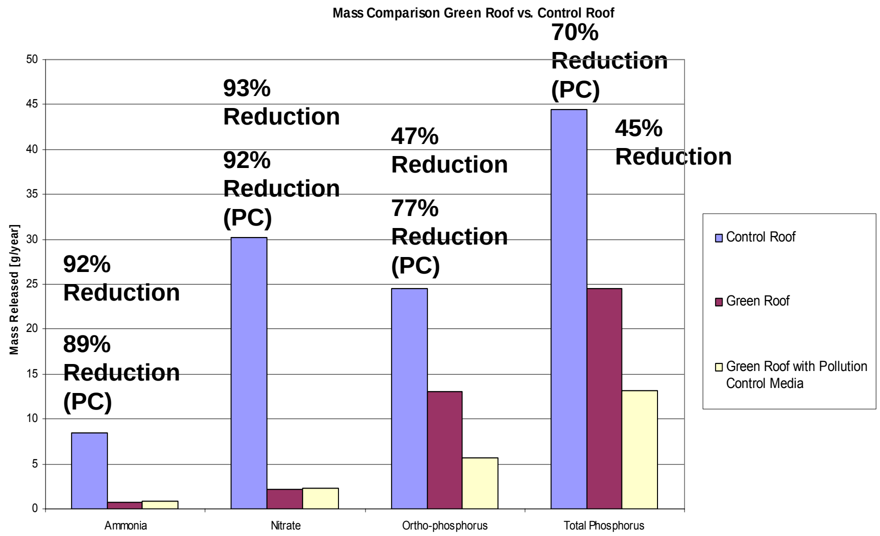
Example Problem (Cont.)

- Irrigation required to ensure plant survival
  - Surface drip irrigation to be used
    - 1.5 inches per week for the summer months
    - 1 inch per week for the spring and fall months
    - 0.5 inches per week for the winter months
- Native ground cover to be used
  - Depth restrictions
- Size cistern using Orlando design curve

Example Problem (Cont.)

- Efficiency needed is 80%
  - Cistern to store 2.5 inches over the green roof area (80% volume reduction)
    - volume of 1250 gallons
- Based on average year precipitation is 50 inches
  - Volume off a control roof is about 24,500 gallons

Example Problem (Cont.)



Example Problem (Cont.)

- This green roof stormwater treatment system design meets all of the design criteria set forth by this problem.
- If further nutrient removal is required a larger cistern or a treatment train should be used.

Thank You For Your Time

9th Biennial Conference on Stormwater Research and Watershed Management

University of Central Florida Stormwater Management Academy
"Managed Stormwater is Good Water"

Department of Environmental Protection FLORIDA

Questions?

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