Stormwater Non-potable Beneficial Uses: Modeling Groundwater Recharge at a Stormwater Drywell Installation

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Introduction

- Besides the obvious benefit of reduced stormwater discharges (and attendant receiving water benefits), many stormwater use options also benefit other components of the urban water infrastructure.
- If stormwater is stored and used to irrigate landscaped areas and flush toilets, as is common in many water-stressed locations today, less highly treated domestic water needs to be delivered.
- Groundwater recharge to augment local groundwater resources, possibly for later local use as demonstrated in many developing countries, is also a suitable beneficial use of stormwater.

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Millburn, NJ (Background)

- For the past several years, the city of Millburn has required dry wells/cisterns to infiltrate the increased flows from newly developed areas.
- There are some water storage tanks now being installed to use the increased stormwater for irrigation.
- The current project supported by the Wet Weather Flow Research Program of the US EPA is investigating whether increased beneficial uses of the runoff would be a more efficient use of the water instead of infiltrating into the shallow groundwaters.
- There are substantial data available for this community, and we are supplementing these data with more detailed site information to allow a comprehensive review of beneficial stormwater uses.

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- This EPA project in Millburn includes monitoring the water levels in several dry wells and concurrent rainfall conditions. This information is also being used to calibrate WinSLAMM for detailed evaluations of alternative stormwater management options, including beneficial water use (irrigation and groundwater recharge).
- This information, along with the rainfall and evapotranspiration data, will be used to calculate the amount of stormwater that can be beneficially used for local groundwater recharge and site irrigation and to show how landscaping irrigation needs integrates with the available rainfall.

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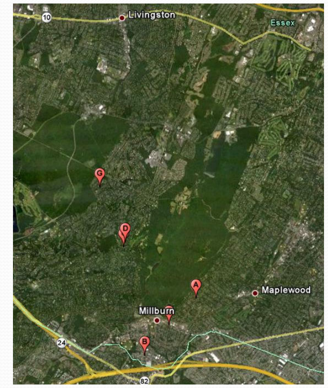
Location of monitoring dry wells

	Address
A	383 Wyoming Avenue, Millburn, NJ.
B	258 Main St., Millburn, NJ.
C	11 Fox Hill Ln, Millburn, NJ.
D	8 South Beechcroft Rd., Millburn, NJ.
E	2 Undercliff Rd. , Millburn, NJ.
F	Linda's Flower, Millburn, NJ.
G	9 Lancer, Millburn, NJ.



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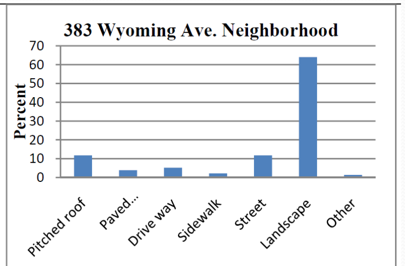
Land Development Characteristics (a sample site)



Most of areas covered by landscape (grass + trees)

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Soil (sourc: online soil survey, USDA)

Address	Soil Name	Soil Group	Slope (%)	K_{sat}	Drainage class	Typical profile
383 Wyoming Ave.	Boonton-Urban land, Boonton substratum complex, red sandstone	C	3-8	Moderately low to moderately high (0.06 to 0.20 in/hr)	Well drained	0 to1 in: Slightly decomposed plant 1-3 in: Silt loam 3-10 in: Loam 10-27 in: Gravelly loam 27-67 in: Gravelly fine sandy loam 67-83 in: Gravelly sandy loam
258 Main St.	Dunellen sandy loam	A	3-8	High (1.98 to 5.95 in/hr)	Well drained	0-42 in: Sandy loam 42-70 in: Stratified gravelly sand to sand to loamy sand
11 Fox Hill Ln 8 South Beechcroft 2 Undercliff Rd Linda's Flower	Boonton - Urban land, Boonton substratum complex, terminal moraine	C	3-8	Moderately low to moderately high (0.06 to 0.20 in/hr)	Well drained	0-1 in: Highly decomposed plant 1-24 in: Sandy loam 24-42 in: Gravelly sandy loam 42-60 in: Fine sandy loam
9 Lancer	Boonton - Urban land, Boonton substratum complex	C	8-15	Moderately low to moderately high (0.06 to 0.20 in/hr)	Well drained	0-5 in: Loam 5-30 in: Silt loam 30-40 in: Gravelly fine sandy loam 40-47 in: Fine sandy loam 47-72 in: Loamy sand

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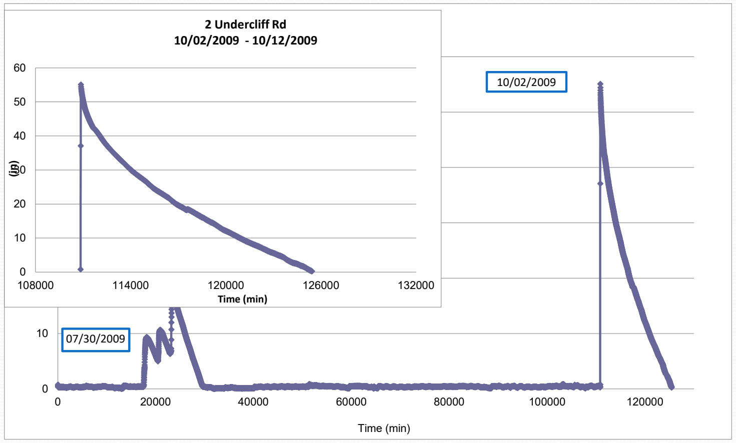
Example site infiltration during a two month monitoring period



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Infiltration

- Horton (1940)

$$f = f_c + (f_o - f_c)e^{-kt}$$

f: the infiltration rate at time t (in/hr),
f_o: the initial infiltration rate (in/hr),
f_c: the final infiltration rate (in/hr),
k: first-order rate constant (hr^{-1}).

This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time

- Green–Ampt (1911)

$$f_t = K\left(\frac{\psi \Delta \theta}{F_t} + 1\right)$$

f_t : infiltration rate, cm/hr;
ψ : the initial Matric potential of the soil, in;
Δθ: the difference of soil water content after infiltration with initial water content, in^3/in^3;
K: hydraulic conductivity, in/hr;
F_t is the cumulative infiltration at time t, in.

This equation requires a linear relationship between ft and ($1/F_t$)

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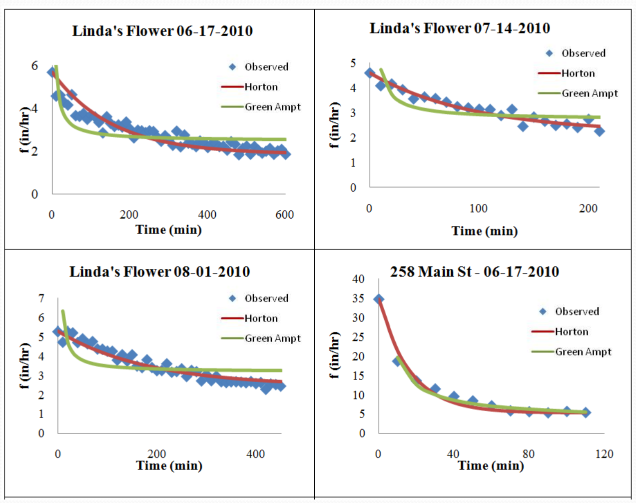

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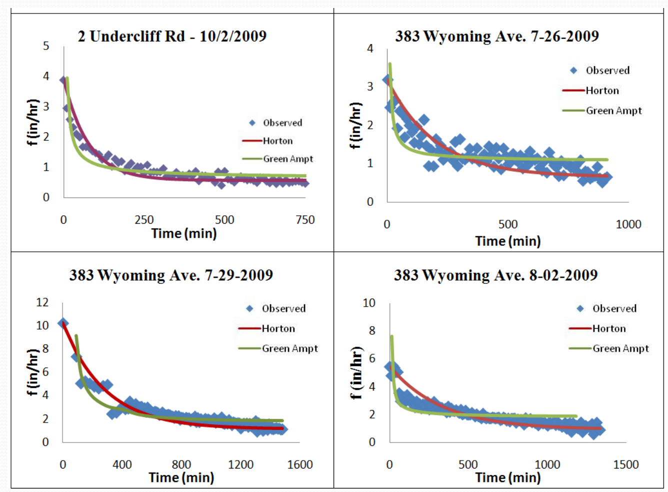

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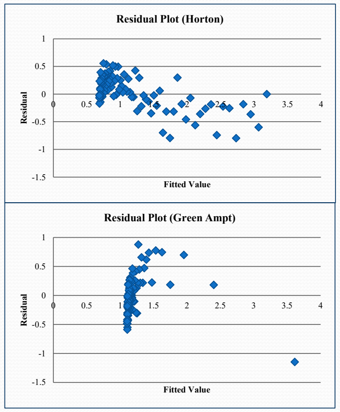
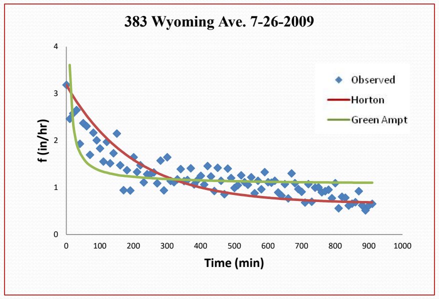
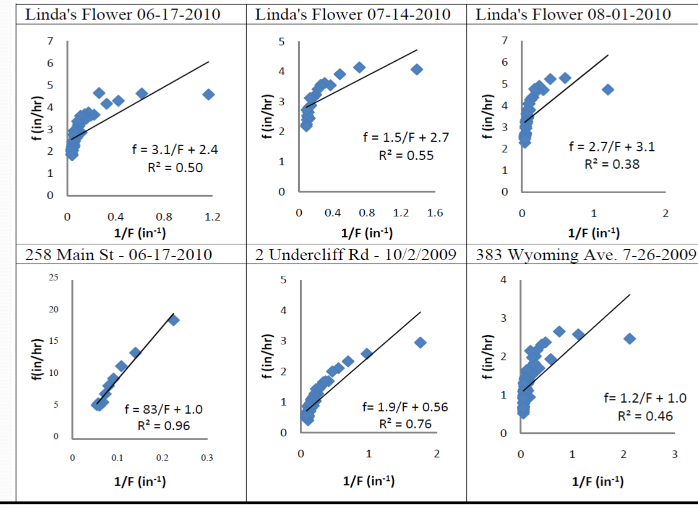
Residual Plots for Horton and Green Ampt fitted values (383 Wyoming Ave.)





Linear regression of f_t vs (1/F) for some sites in Millburn, NJ.

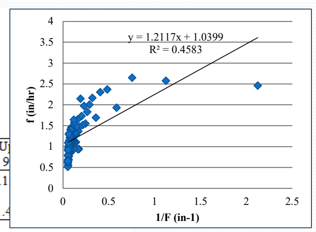


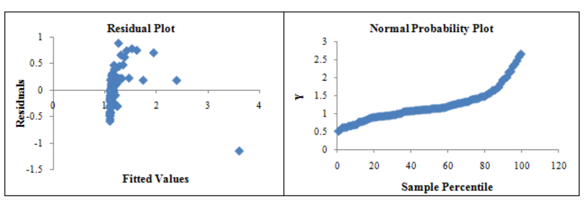
Regression Analysis for f vs. 1/F -Green Ampt (383 Wyoming Ave.)

ANOVA

	df	SS	MS	F	Significance F
Regression	1	8.909624	8.909624	75.30019	1.75E-13
Residual	89	10.5306	0.118321		
Total	90	19.44023			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	U... 9...
Intercept	1.039948	0.042319	24.57386	1.97E-41	0.95586	1.1
X Variable 1	1.211721	0.139638	8.677568	1.75E-13	0.934263	1.4





Horton's Parameters summery

Site Address	Soil Group	Date	Horton's parameters (Millburn observed data)			Akan (1993)	Pitt et al. (1999)*		
			f_0(in/hr)	f_c(in/hr)	k (1/min)	f_0(in/hr)	f_0(in/hr)	f_c(in/hr)	k (1/min)
Linda's Flower	C	06-17-2010	5.7	1.9	0.0065	2-6	1.0-3.75	0.0-0.5	0.03-0.1
		07-14-2010	5.6	2.2	0.011				
		08-01-2010	5.3	2.5	0.0055				
258 Main St.	A	06-17-2010	35	5.3	0.06	6-10	1.5-12	0.25-1.3	0.05-0.2
		07-14-2010	75	6.8	0.07				
		08-01-2010	75	4.7	0.045				
2 Undercliff	C	10-02-2009	3.9	0.57	0.013	2-6	1.0-3.75	0.0-0.5	0.03-0.1
383 Wyoming Ave.	C	7-26-2009	3.2	0.66	0.005	2-6	1.0-3.75	0.0-0.5	0.03-0.1
		7-29-2009	10	1.1	0.0035				
		8-02-2009	5.5	0.93	0.003				
		8-22-2009	3.6	1.2	0.03				
		10-02-2009	5.6	1.2	0.0045				

* 25th and 75th percentile values for compact sandy conditions

Green-Ampt parameters

Site Address	Date	Hydraulic conductivity K (in/hr)	
		Millburn (case study)	Rawls et al. (1983)
Linda's Flower	06-17-2010	2.435	0.429
	07-14-2010	2.685	
	08-01-2010	3.131	
258 Main St.	06-17-2010	1.018	1.17
2 Undercliff	10-02-2009	0.557	0.429
383 Wyoming Ave.	7-26-2009	1.039	0.13-0.43

- For the rest of sites "K" values estimated from fitted curves were *negative*.

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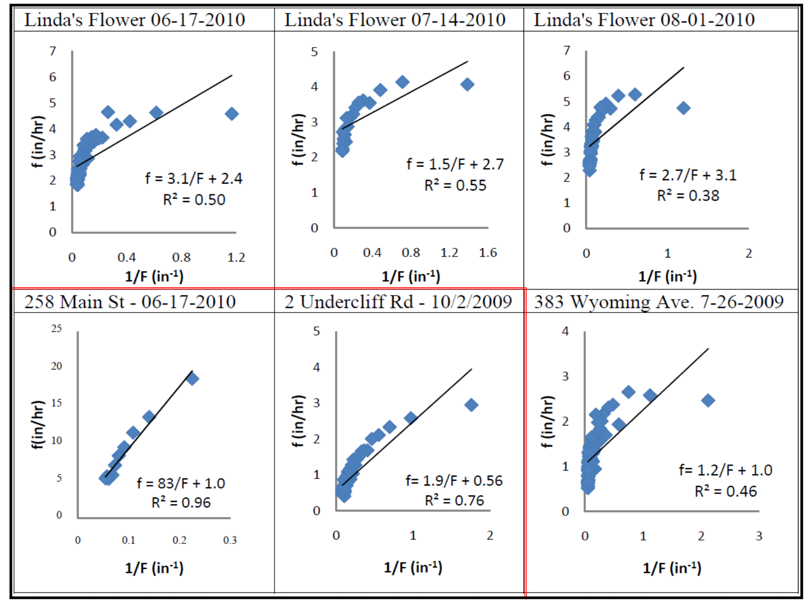

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Conclusion

- The fitted graphs and resulting derived parameters of each mentioned equations indicate that although the fitted Horton curve is **visually** fitted better to observed data of the case study area than Green-Ampt curve, the **calculated parameters** of both used infiltration models **don't compare to the literature**.
- It is necessary to have **local measured data** for modeling and don't rely only on literature values.
- Later project activities will involve extensive modeling of stormwater beneficial use opportunities at many US locations, including Millburn, NJ with WinSLAMM model, resulting sustainable water management to make top-level evaluations of this water source.

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Thank You

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