Evaluation and Demonstration of the Performance of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey

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Education

- B.S., Civil Engineering, Polytechnic University of Tehran, Iran, 2004
- M.S., Civil Engineering, Khajeh Nasir Toosi University of Technology, Iran, 2007
- Ph.D. Student, Civil Engineering, University of Alabama, 2010-present

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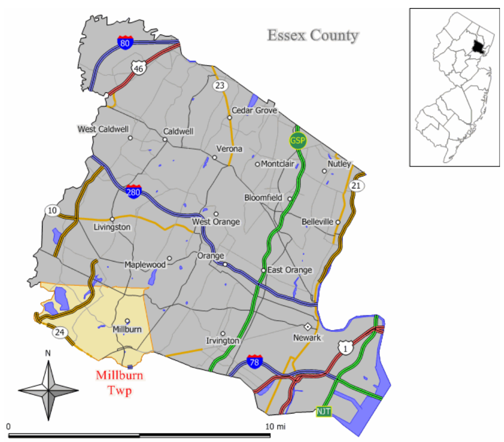
Description of the Township of Millburn, NJ

- Population: 20,149 (2010 US census)
- 5,900 detached homes
- 1,500 dry wells



http://upload.wikimedia.org/wikipedia/commons/5/58/Millburn_twp_nj_013.png

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Dry Wells in Millburn, NJ

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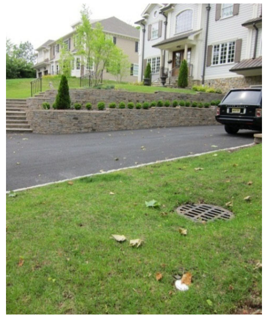
Objectives

To investigate the effectiveness of Millburn's stormwater management practices that rely on the use of dry wells limiting stormwater discharges into the local drainage system.



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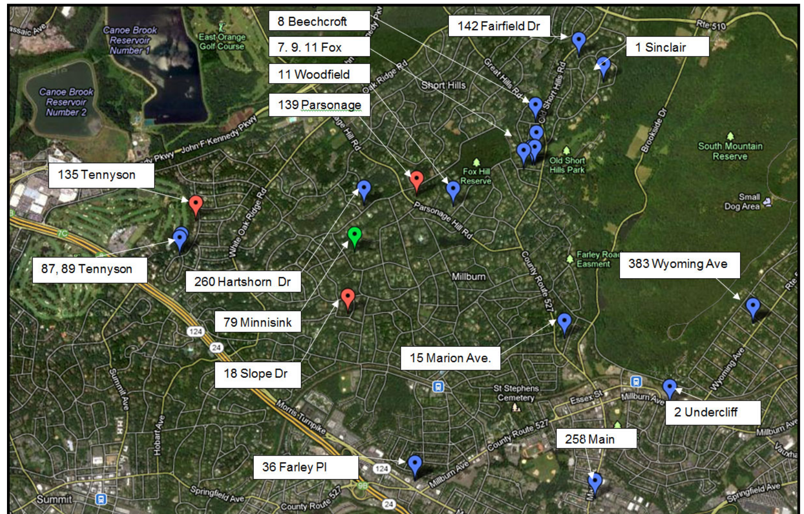

Monitored dry wells (blue icons), cistern (green icon), and newly constructed dry wells outfitted for water quality monitoring (red icons)

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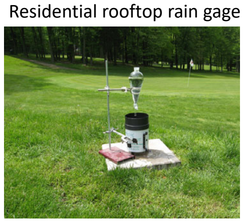
Rain Gauges

Residential rooftop rain gage

Roof of Township's maintenance garage



Municipal Par 3 Golf Course

Old tennis court at Greenwood Gardens

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New Jersey State Dry Well Regulations

- A or B soils needed with associated minimum 5 to 12 mm/hr (0.2 to 0.5 in./hr) infiltration rates
- Depth to the seasonal water table or bedrock: at least 2 ft below the infiltration system
- Restrict the source waters for infiltration to be roof runoff only.

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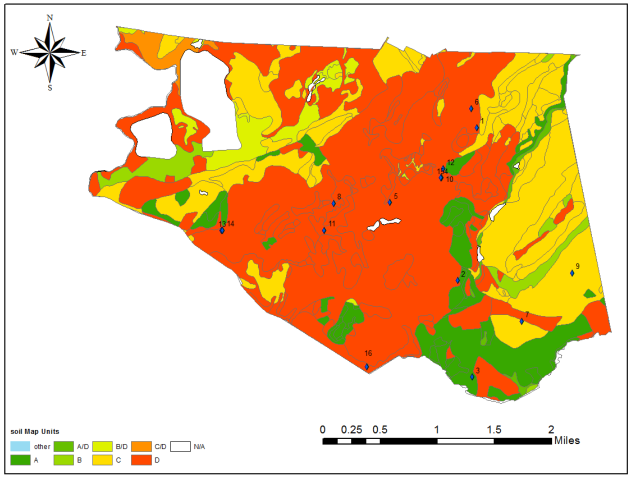
Hydrologic Soil Group Index of the Township of Millburn for Surface Soils



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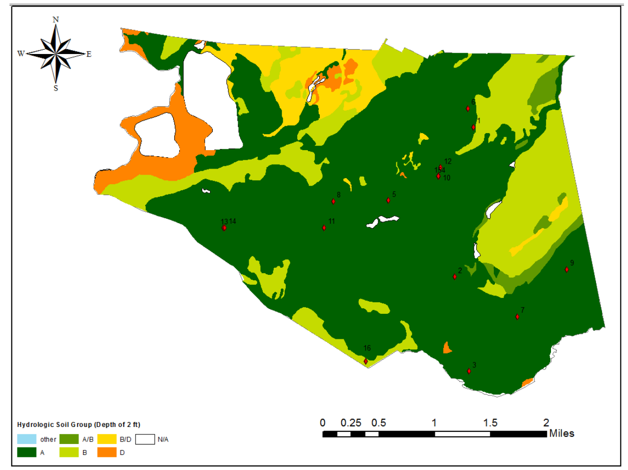
Hydrologic Soil Group Index of the Township of Millburn for Shallow Subsurface Soils 2 ft Deep



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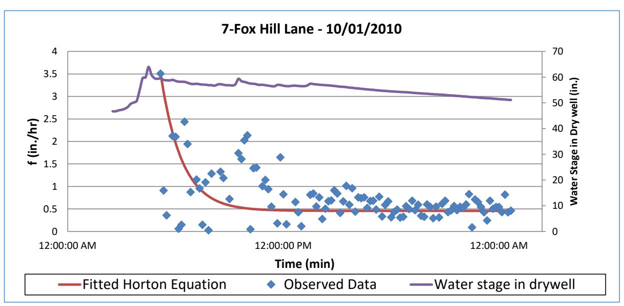
Infiltration Data Analysis

Horton's Equation

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

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



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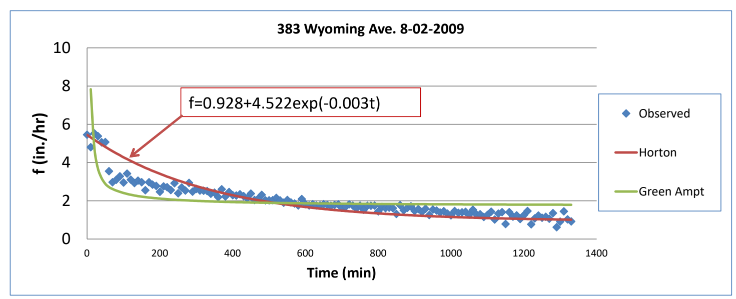
Infiltration Data Analysis

Green-Ampt Equation

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

f_t is infiltration rate, in./hr;
y is the initial matric potential of the soil (in.);
DQ is the difference of soil water content after infiltration with initial water content (in.^{3}/ in.^{3});
K is hydraulic conductivity (in./hr); and F_t is the cumulative infiltration at time t (in.).



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Mann-Whitney Test

- **Non-parametric tests:** If the data are not normally distributed, or the distribution is unknown or mixed
- The probability of two populations' medians being the same (within the confidence interval) is calculated.
- **Assumptions:** the data are independent random samples from two populations that have the same shape

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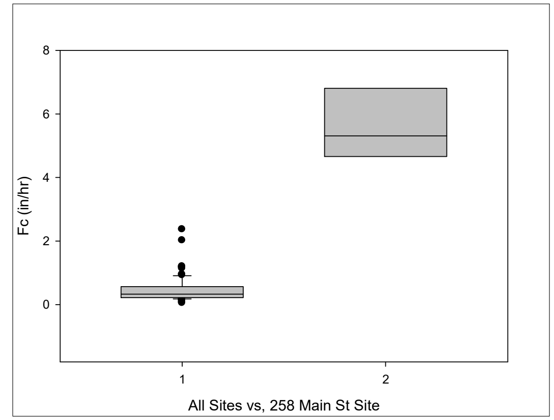
Infiltration Data Analysis

Statistical Groupings of Site Data for Horton Coefficients

P=0.004



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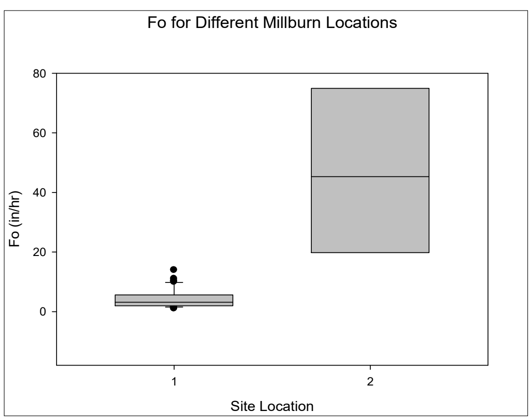
Infiltration Data Analysis

Statistical Groupings of Site Data for Horton Coefficients

P<0.001



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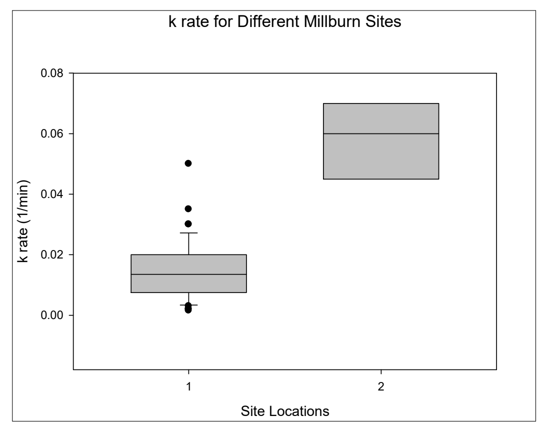
Infiltration Data Analysis

Statistical Groupings of Site Data for Horton Coefficients

P=0.005



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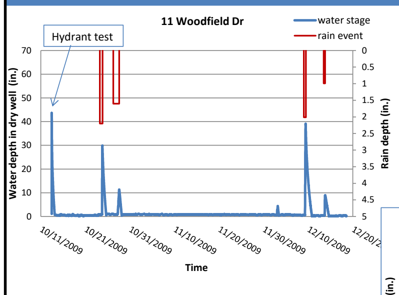
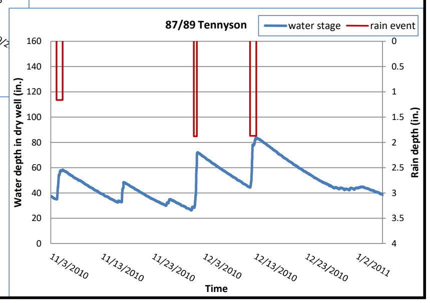
Standing Water Conditions in Dry Wells



No standing water after all events

High water conditions after all events



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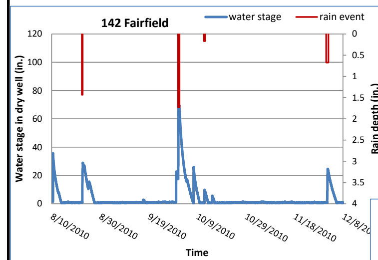
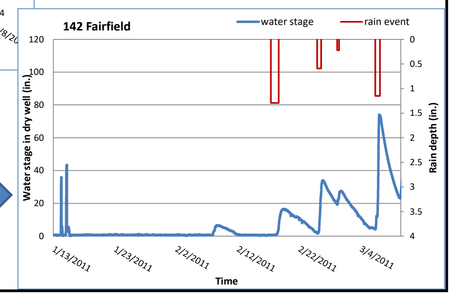
Standing Water Conditions in Dry Wells



No standing water after some events

Same site: Possible mounding of water table conditions after some events (very wet period)



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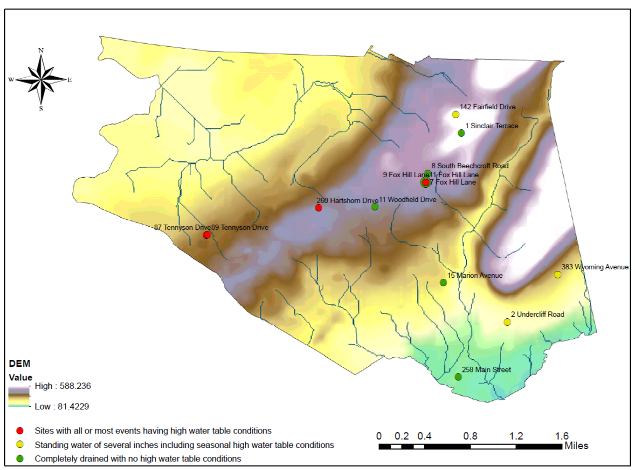
Water Table Conditions in Dry Wells



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Water Table Conditions in Dry Wells

- Sites having no standing water after the events (completely drained with no apparent high water table conditions): 11 Woodfield Dr, 15 Marion, 258 Main St, 1 Sinclair Terrace (only one observation), 8 South Beechcroft Rd, 11 Fox Hill Lane (only one observation), 36 Farley Place
- Sites having a few standing water conditions after the events (standing water of several inches, or more, indicating possible seasonal high water table conditions): 2 Undercliff Rd, 383 Wyoming Ave., 142 Fairfield Dr.
- Sites with all or most events having high water conditions: 260 Hartshorn Dr , 87/89 Tennyson Dr, 7 Fox Hill Lane, 9 Fox Hill Lane

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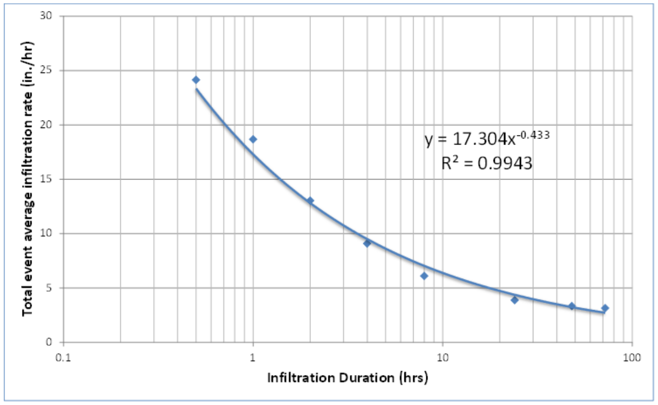
The Township of Millburn infiltration rate characteristics

A and B surface soils and having well drained HSG A subsurface soils



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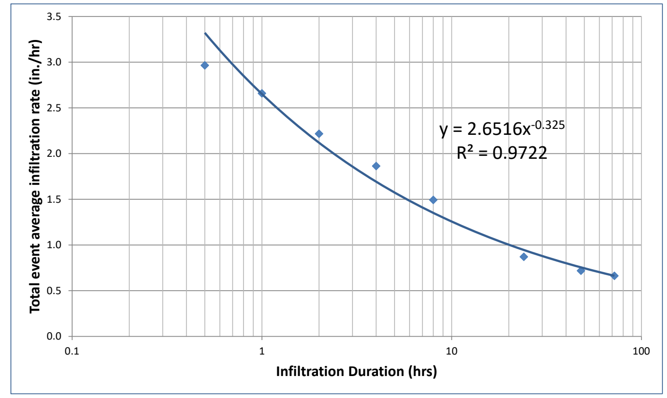
The Township of Millburn infiltration rate characteristics

C and D surface soils and having well drained A and B subsurface soils



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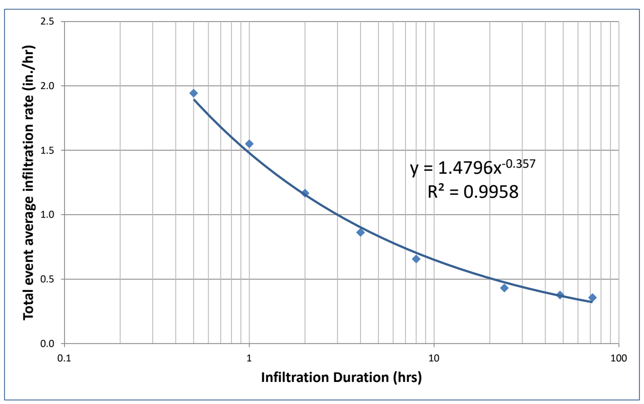
The Township of Millburn infiltration rate characteristics

C and D surface soils and having poorly drained A and B subsurface soils with long-term standing water



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Observed Infiltration Coefficient Values Compared to Literature Values

	f_o (in./hr)	f_c (in./hr)	K (1/min)
Surface A and B soils well drained A subsurface soils (average and COV)	44.6 (0.53)	5.6 (0.2)	0.06 (0.22)
Surface C and D soils well drained A and B subsurface soils (average and COV)	4.3 (0.64)	0.45 (0.85)	0.01 (0.63)
UDFCD (2001) A soils (average)	5.0	1.0	0.04
UDFCD (2001) B soils (average)	4.5	0.6	0.11
UDFCD (2001) C and D soils (average)	3.0	0.5	0.11
Pitt, et al. (1999) Clayey, dry and non-compacted (median)	11	3	0.16
Pitt, et al. (1999) Clayey, other (median)	2	0.25	0.06
Pitt, et al. (1999) Sandy, compacted (median)	5	0.5	0.1
Pitt, et al. (1999) Sandy, non-compacted (median)	34	15	0.08
Akan (1993) Sandy soils with little to no vegetation	5		
Akan (1993) Dry loam soils with little to no vegetation	3		
Akan (1993) Dry clay soils with little to no vegetation	1		
Akan (1993) Moist sandy soils with little to no vegetation	1.7		
Akan (1993) Moist loam soils with little to no vegetation	1		
Akan (1993) Moist clay soils with little to no vegetation	0.3		

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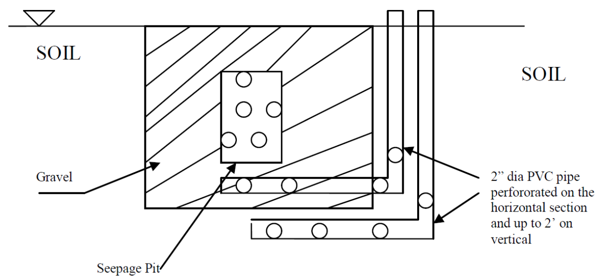
Water Quality



- Three dry wells: a shallow monitoring well and a deep monitoring well
- A new water storage cistern: sampled at the inlet and from the outlet.
- 8 to 10 storms were sampled (all samples were analyzed in duplicate.)

Water Quality – Methods and Materials

- The samples were analyzed in laboratories of the University of Alabama for bacteria: (total coliform and *E. coli* screening analyses), total nitrogen (TN), nitrate plus nitrite (NO_3 plus NO_2), total phosphorus (TP), and chemical oxygen demand (COD).
- Lead, copper, and zinc were analyzed at a commercial laboratory (Stillbrook Environmental Testing Laboratory in Fairfield, AL).
- Selected samples were also analyzed for pesticides by the EPA (not reported here).

Water Quality – Methods and Materials

Rain Depths for Monitored Events (all relatively small during this dry period, except for the record rainfall during Hurricane Irene)

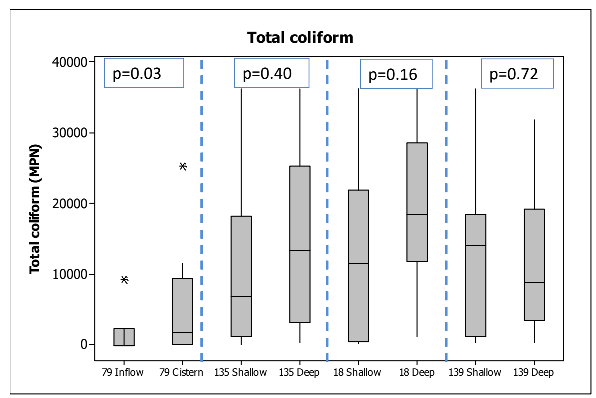
Date	Rain Depth
10/20/2010	0.10 in.*
7/29/2011	0.15 in.*
8/5/2011	0.14 in.*
08/10/2011	0.12 in.*
08/16/2011	0.15 in.
08/17/2011	0.20 in.
08/18/2011	0.10 in.
08/22/2011	0.50 in.
08/25/2011	0.25 in.
08/28/2011**	9 in.

*The data from these rains was obtained from http://www.wunderground.com/ while the other rains were obtained from the on-site rain gages.

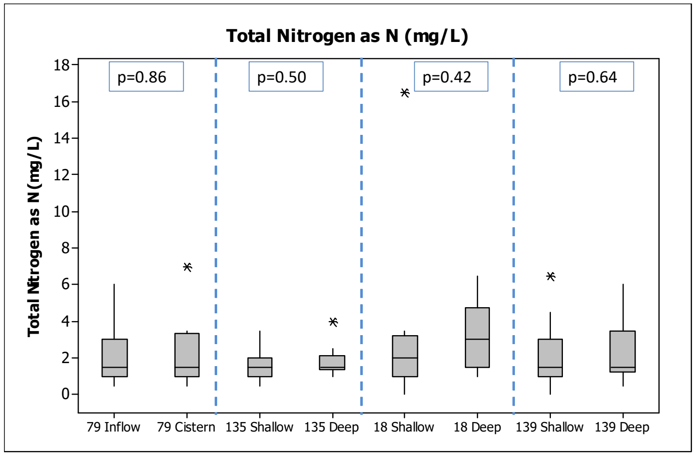
**Hurricane Irene rain began about 3:00 pm on 08/27/2011 and finished at about 10:00 am on 08/28/2011, producing record rainfall for the area. (1 in. = 25.4 mm)

Bacteria

IDEXX method within 24 hr of sampling (undiluted UDL: 2,419 MPN/100 mL, or 24,192 with 10X dilutions and 48,384 with 20X dilutions)



Nutrients



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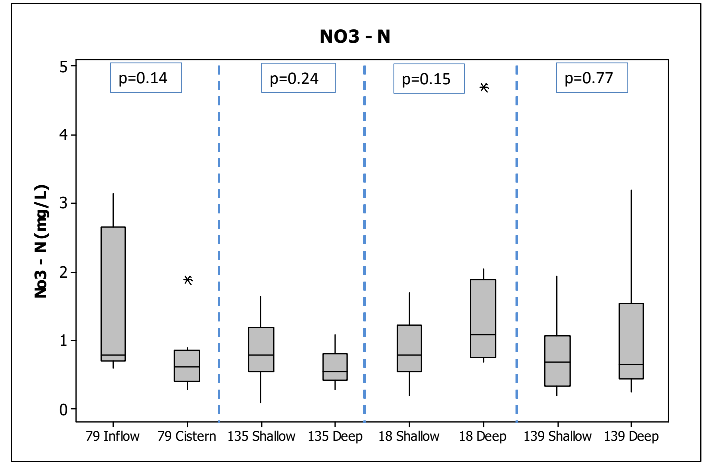
Nutrients



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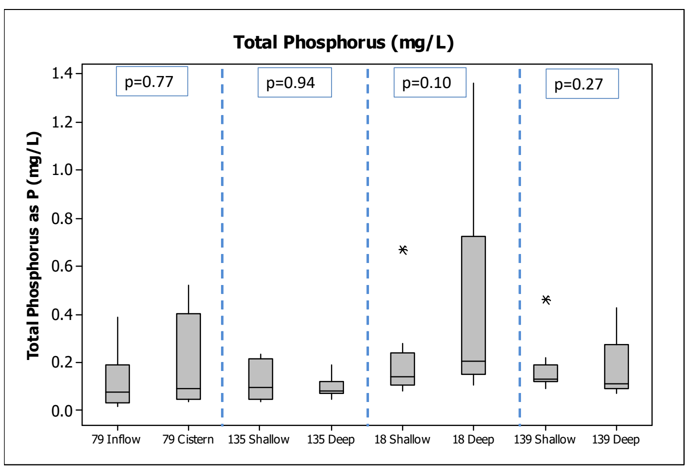
Nutrients



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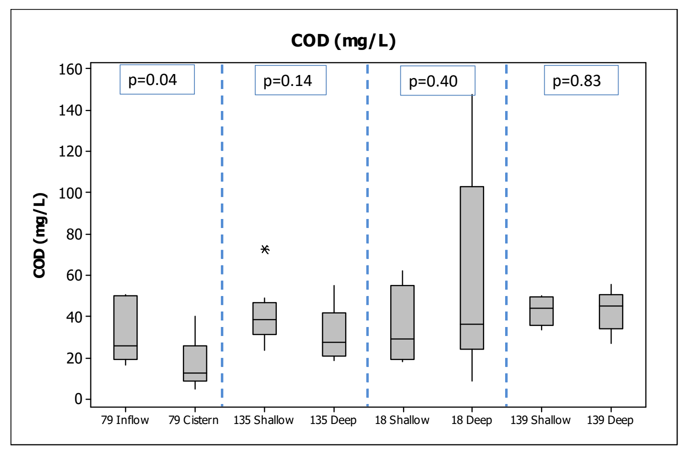
Chemical Oxygen Demand (COD)



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Metals

- Many were below the method detection limit (BDL).
- The maximum observed concentration for lead (380 µg/L) occurred in a deep monitoring well sample under a dry well.
- The maximum observed concentration of copper (1,100 µg/L) occurred in a cistern influent sample (possibly due to copper roof gutters on the home).
- The concentrations of zinc in all samples ranged from BDL to 140 µg/L.

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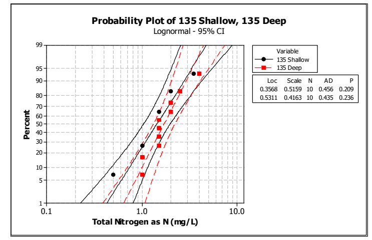
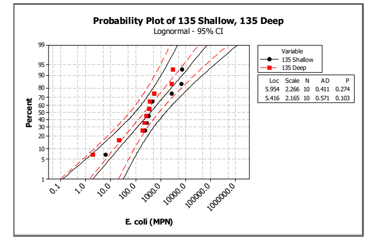
Log-normal Probability Plots and Anderson-Darling Test Statistics





- Most of the data are seen to overlap within the limits of the 95% confidence limits, indicating that the data are likely from the same population.
- The data seem to generally fit a straight line on log-normal plots, indicating likely log-normal data distributions, and as supported by the Anderson-Darling test statistic.

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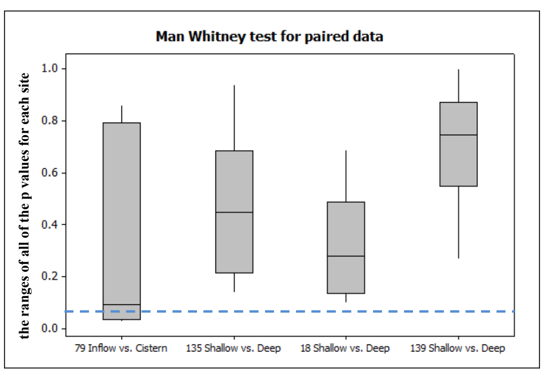
Mann Whitney Test

Except for the bacteria and COD results for the cistern site, all paired sample sets did not indicate significant differences for these numbers of samples at the 0.05 level.



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Summary of Paired Sign Test for Metal analysis

Metal	79 Inflow vs. 79 Cistern	135 Shallow vs. 135 Deep	18 Shallow vs. 18 Deep	139 Shallow vs. 139 Deep
Lead	> 0.06	> 0.06	0.18	> 0.06
Copper	0.125	*	>0.06	*
Zinc	0.45	0.45	>0.06	>0.06

* All the results are below the detection limit (BDL), therefore it is not possible to do a statistical comparison test

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Groundwater Quality Criteria for the State of New Jersey Compared to Observed Water Quality from Dry Wells (mg/L)

Constituent	Groundwater Quality Criterion	Observed Range	Fraction of samples that exceed the criteria
Microbiological criteria	Standards promulgated in the Safe Drinking Water Act Regulations (N.J.A.C. 7:10-1 et seq.): 50 MPN/100 mL	Total coliform: 1 to 36,294 MPN/100 mL E. coli: 1 to 8,469 MPN/100 mL	Total coliform: 63 of 71 samples exceeded the criterion for total coliforms E. coli: 45 of 71 samples exceeded the criterion for E. coli
Nitrate and Nitrite	10	0.0 to 16.5 (one sample had a concentration of 16.5 mg/L)	1of 71 samples exceeded the criterion for nitrates plus nitrites
Nitrate	10	0.1 to 4.7	0
Phosphorus		0.02 to 1.36	
COD		5.0 to 148	
Lead	0.005	BDL to 0.38	33 of 71 samples exceeded the criterion for lead
Copper	1.3	BDL to 1.1	0
Zinc	2.0	BDL to 0.14	0

Conclusion

- The Horton equation usually had a better fit to the data compared to the Green-Ampt equation for the Millburn dry well infiltration data.
- The infiltration rate characteristics were separated into three conditions:
  - **A and B surface soils having well drained HSG A subsurface soils**
  - **C and D surface soils having well drained A and B subsurface soils**
  - **C and D surface soils having poorly drained subsurface soils with long-term standing water**

Conclusion

- No significant differences in water quality between the deep samples and shallow samples in dry wells (p values were > 0.05).
- If the influent water quality is of good quality, the dry wells can be a safe disposal method for stormwater quality.
- However, the bacteria and lead concentrations exceeded the groundwater disposal criteria for New Jersey
- Significant differences (p< 0.05) between the quality of inflow samples and cistern samples for total coliform and *E. coli* (increased values possibly indicating re-growth), and COD (reduced values).

Conclusion

- The deep monitoring well samples were located at least 1.3 m (4 ft) below the bottom of the dry well (at least 2 ft in the soil). This distance was not sufficient to result in observed significant reductions in the stormwater constituents.
- Rain gardens or biofilters as alternatives:
  - Provide better groundwater protection
  - Receive runoff from several of the source areas