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

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Since 1999, the city of Millburn has required dry wells to accommodate additional flows from newly developed areas to mitigate local drainage and water quality problems. The primary objective of this EPA funded project was to investigate the effectiveness of the Township of Millburn's use of on-site dry wells to limit stormwater flows into the local drainage system. This objective was achieved by collecting and monitoring the performance of dry wells during both short and long-periods. The water quality beneath dry wells and in a storage cistern was also monitored during ten rain events.

There were varying levels of dry well performance in the area, but most were able to completely drain within a few days. However, several had extended periods of standing water that may have been associated with high water tables, poorly draining soils (or partially clogged soils), or detrimental effects from snowmelt on the clays in the soils. The infiltration rates all met the infiltration rate criterion of the state guidelines for stormwater discharges to dry wells, but not the state regulations that only allow roof runoff to be discharged to dry wells and those that prohibit dry well use in areas of shallow water tables. Overall, most of the Millburn dry wells worked well in infiltrating runoff. The dry well findings reported in this paper indicate that the dry wells did not significantly change any of the water quality concentrations in the subsurface water exiting the dry wells compared to the influent water. The cistern system did result in significant reductions in bacteria levels. Although the dry wells provided no significant improvements in water quality for constituents of interest for the infiltrating water, they resulted in reduced mass discharges of flows and pollutants to surface waters and reduced runoff energy, a major cause of local erosion problems.

1.1 Description of Millburn and Its Dry Wells

The Township of Millburn, Essex County, NJ, is located near New York City, and is less than 10 miles from the Newark International Airport. The 2010 US census indicated the township had a population of 20,149. Housing costs are very high (According to Wikipedia, Millburn had the highest annual property tax bills in New Jersey in 2009 at an average of more than $19,000 per year, compared to the statewide average property tax that was $7,300 which was the highest statewide average in the country). There are about 5,900 detached homes in the township and about 1,500 have dry wells.

In 1999, the Township of Millburn created an ordinance that required increased runoff from new impervious areas to be directed into seepage pits (dry wells). The purpose of this project was to investigate the effectiveness of this ordinance, specifically to examine the use of dry wells as a technique to redirect surface runoff to the local shallow groundwater. The objective of this approach is to reduce local drainage and erosion problems associated with new development and increased impervious areas of currently developed areas. The slower release of the shallow groundwater to surface streams also better simulates natural hydrologic patterns with reduced in-stream problems associated with increased rapid surface runoff. The Township of Millburn has a stable population and there is little vacant land; all new construction within the community occurs on previously developed plots.

The Millburn Township stormwater regulations (in their *Development Regulations*) list dry wells as one option for minimizing increased flows associated with new (and increased) development. They do not include any specific criteria for their use, except for a statement pertaining to a 60 cm (2 ft) blanket of crushed stone surrounding the dry well. Specifically, they do not describe applicable soil characteristics, groundwater conditions, or suitable source waters. The New Jersey state stormwater regulations also requires the infiltration of excess water above natural conditions associated with development or land modifications (either maintaining the pre-development groundwater recharge or preventing excess surface runoff). The state dry well regulations describe the construction of the dry wells, the acceptable soil conditions (NRCS hydrologic soil groups, HSG, A and B), groundwater conditions (at least 60 cm or 2 ft above seasonal water table), and source waters (roof runoff only).

A dry well is a subsurface infiltration stormwater disposal practice that receives stormwater runoff from surrounding areas for subsurface disposal to shallow groundwater. Most of the dry wells in the Township of Millburn are precast concrete structures (Figure 1.1), with open bottoms resting on 0.6 m (2 ft) crushed stone layers and with 0.6 m(2 ft) of crushed stone surrounding the dry wells. Most of the dry wells receive water directly from roof drain leaders or by storm drain inlets located in driveways or small parking lots. Some also have grated covers and receive surface runoff from the surrounding lawn or paved areas.

Figure 1.1 Peerless Concrete Products, Butler, NJ, supplies the dry wells to many of the sites in Millburn (photo from http://www.peerlessconcrete.com/)

Figure 1.1 shows typical dry well installations. Many of the dry wells are located in landscaped areas and have open covers, allowing surface runoff from the lawns to enter the dry wells, as well as the subsurface piped roof runoff. Some are also located in paved areas, also allowing surface runoff from the driveways to enter along with the roof runoff.

Figure 1.2 Typical Millburn dry well locations in front yards receiving lawn area inflows along with roof runoff.

1.2 Methodology

1.2.1 Infiltration Tests at Millburn Dry Well Installations

Infiltration tests were conducted during two project phases: the first phase filled the dry wells with domestic water from township fire hydrants and the decreasing water levels were recorded; the second phase used continuous water level monitoring in a fewer number of dry wells during many rains. The infiltration measurements were conducted using continuous recording (10 minute observations) LeveLoggers by Solintest that were installed in the dry wells. The short-term tests were conducted in many dry wells throughout the township to measure the influence of many of the conditions present in the community. The long-term tests were conducted in fewer dry wells (based on the number of LeveLoggers available). These were installed for several months to over a year at each monitored location and continuously recorded the water levels in the dry wells every 10 minutes during and between rains. Close-by rain gages were also used to record local rains associated with these events. These rain and water level data were downloaded by PARS Environmental personnel and uploaded to their ftp website where University of Alabama researchers downloaded the data for analysis.

The first step in the data analyses of the long-term tests was to plot the data as time series. The infiltration characteristics of the dry well installations were calculated from the recession curves of these individual rain events. The infiltration rates for each ten minute step were calculated based on the drop in water level per time increment, resulting in infiltration rate plots of in./hr vs. time since the peak water level. These are classical infiltration rate plots and statistical analyses were used to calculate infiltration rate equation parameters for two common infiltration equations (Horton and Green-Ampt).

Groundwater recharge is a suitable beneficial use of stormwater in many areas as it is used to augment local groundwater resources. This study showed how the dry wells could be very effective in delivering the stormwater to the groundwater. Even though the surface soils were almost all marginal for infiltration options, the relatively shallow dry wells were constructed into subsurface soil layers that had much greater infiltration potentials. However, some of the monitored dry well locations experienced seasonal high groundwater elevations, restricting complete draining of the dry wells after rains. While surface and subsurface soil information is readily available for the Township (and in most other areas of the country), the presence of the shallow water table (or bedrock) is not well known. This makes identifying the most suitable locations for dry wells difficult, as the seasonal groundwater should be at least 4 m (12 ft) below the ground surface (or 60 cm, 2 ft, below the lowest gravel fill layer beneath the dry well: 2 ft of surface cover, 6 ft dry well concrete structure, 2 ft lower gravel layer, and 2 ft of separation above the high seasonal groundwater depth).

Calculating the benefits of the dry wells (including developing sizing requirements) requires the use of an appropriate infiltration equation, preferably as part of a continuous model examining many years of actual rainfall data for a specific area. Two commonly used infiltration equations (Horton and Green-Ampt) were evaluated for their potential use to calculate groundwater recharge at the case study locations in the Township of Millburn, NJ.

One of the most commonly used infiltration equations was developed by Horton (1940). The equation is as follows:

$$f = fc + (f_o - f_c)e^{-kt} \qquad (1)$$

Where 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}). This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber, 1992). This is a reasonable assumption for ponded conditions, such as in the dry wells. The capacity of the soil to hold additional water decreases as the time of the storm increases because the pores in the soil become saturated with water. The Horton equation’s major drawback is that it does not consider the soil water storage availability after varying amounts of infiltration have occurred, but only considers infiltration as a function of time (Akan, 1993). However, integrated forms of the equation can be used that do consider the amount of water added to the soil. It is recommended that f_c, f_o, and k all be obtained through field data, but they are rarely measured locally.

Another common equation for infiltration calculations is by Green-Ampt. The Green-Ampt equation calculates cumulative infiltration as the water flows into a vertical soil profile (Green and Ampt, 1911).

$$f_t = K\left(\frac{\psi \Delta\theta}{F_t} + 1\right) \qquad (2)$$

Where: f_t is infiltration rate, cm/hr; ψ is the initial matric potential of the soil (in.); $\Delta\theta$ 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.). This equation requires a linear relationship between f_t and $(1/F_t)$.

1.2.2 Water Quality Samplings

Water samples were collected at three dry wells and at one cistern during ten rains. The samples were analyzed for nutrients and heavy metals, and selected samples were also tested for pesticides and herbicides. The samples were collected directly below the dry wells (or at the inlet of the cistern) for comparison to water samples collected at least 0.6 m (2 ft) below the 0.6 m (2 ft) gravel layer beneath the dry wells (and in the cistern), for a total subsurface flow path of at least 1.2 m (4 ft) through the crushed stone and subsurface soil (more than the minimum 2 ft separation to the groundwater table as required by the NJ stormwater infiltration regulations). Various statistical tests were used to compare the water quality from the inlet to the outlet locations to detect any significant differences due to operation of the dry wells.

1.3 Results and Discussions

1.3.1 Fitted Infiltration Equations Results for Millburn Dry Well Infiltration Measurements

The initial infiltration data analysis was to prepare plots of the observed infiltration data in order to evaluate major trends and groupings of the data. Observed data included water stage in dry wells every 10 min. The differential values of water stages in a dry well for each event were divided by time to calculate the infiltration rates as a function of time. Data from each site for each event/infiltration test was fitted to the Horton infiltration equation and the equation parameters were derived for f_o, the initial infiltration capacity, f_c, the constant infiltration capacity as t approaches infinity, and k, a soil parameter that controls the rate of decrease of infiltration rate. For some of the sites, the Horton equation was not able to be fitted to the observed data, as little water level change occurred with time. This typically occurred for narrow ranges of the dry well water depth such as when standing water occurred due to shallow water tables. For these conditions, the observed rates most likely corresponded to the f_c values, the saturated infiltration rate (f_o and k were not calculated). Basic statistical analyses, including average, minimum, maximum, standard deviation, and COV are included in the full EPA report (Pitt and Talebi, 2012) for all the data, as well as ANOVA test and residual plots for some of the fitted Horton equations in comparison to Green-Ampt equation.

Figure 1.3 shows the observed infiltration rates and the fitted Horton equation parameter values for the dry well located at 7 Fox Hill Ln, Millburn, NJ, for an example rain event. Graphs are for an actual rain event representing observed data, fitted Horton equations, rain depths, and the water stage in the dry well.

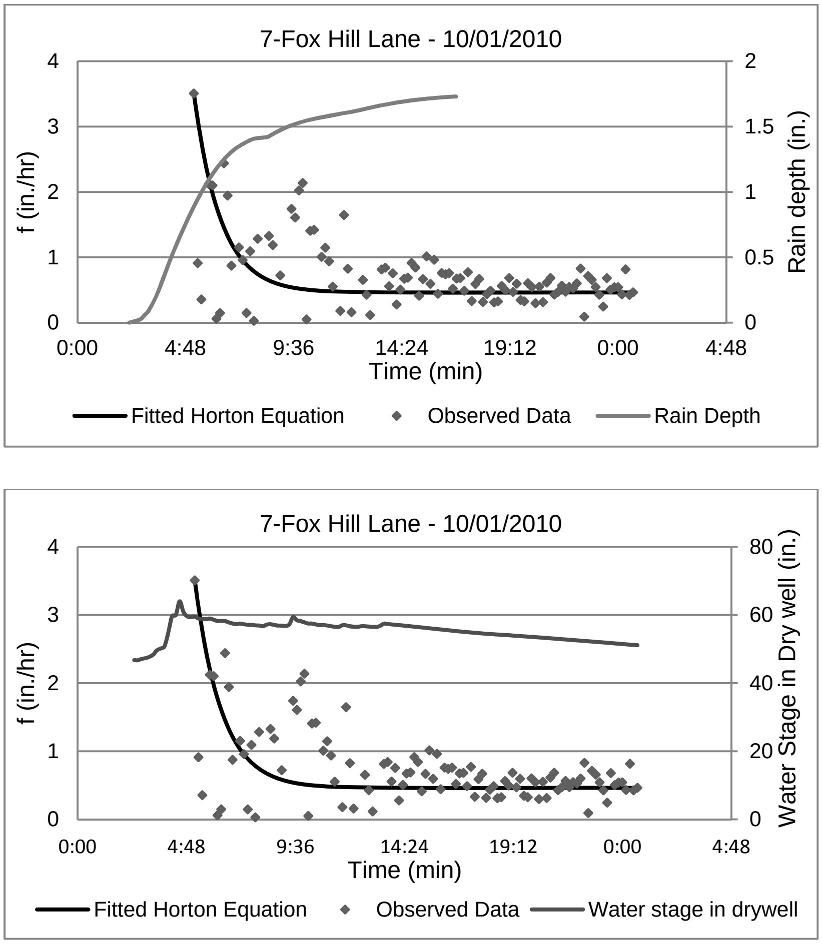

Figure 1.3 Example of observed data, fitted Horton equation, rain depth, and water stage in a dry well for three different rain events in a selected dry well. (1 in./hr = 25.4 mm/hr)

Multiple iterations of grouped box and whisker plots and ANOVA tests were used to identify data groupings. The data were not normally distributed

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so ANOVA based on ranks and Mann-Whitney Rank Sum nonparametric tests were used to calculate the significance that the data did not originate from the same populations.

There were two distinct sets for the f_c data: the 258 Main St location vs. all of the other sites combined. Figure 1.4 shows these two data sets.

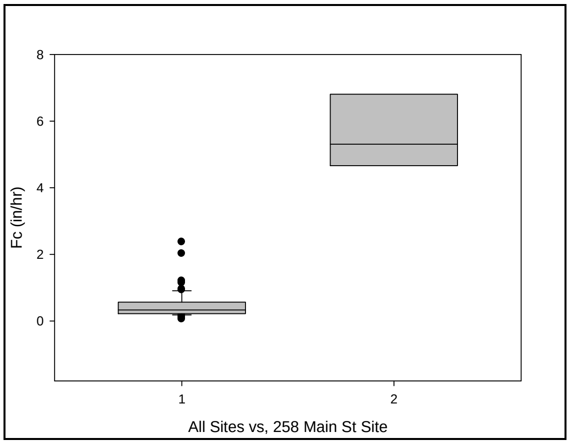

Figure 1.4 Box and whisker plot of f_c data showing two sets of data. (1 in./hr = 25.4 mm/hr)

The results of the final Mann-Whitney Rank Sum test for fc are shown below:

Table 1.1 The results of the final Mann-Whitney Rank Sum test for f_c

Group	N	Missing	Median	25%	75%
Combined	81	0	0.33	0.22	0.57
258 Main	3	0	5.31	4.66	6.81

Mann-Whitney U Statistic= 0.000

T = 249.000; n (small) = 3; n (big) = 81; P = 0.004

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference, with P = 0.004. Tables 1.2 and 1.3 summarize the values and test conditions for these two sets of data.

Table 1.2 f_c summary values and conditions for 258 Main St.

	f_c (in./hr)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	3	3	3	3
Minimum	4.66	0.69	22.32	0.11
Maximum	6.81	1.34	54.77	0.67
Average	5.59	1.08	43.57	0.44
Median	5.31	1.22	53.62	0.53
Std Dev	1.10	0.35	18.41	0.29
COV	0.20	0.32	0.42	0.67

1 in. = 25.4 mm

Table 1.3 f_o summary values and conditions for 258 Main St.

	f_o (in./hr)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	81	63	81	81
Minimum	0.05	0.22	6.51	0.00
Maximum	2.37	2.90	93.85	82.98
Average	0.45	1.20	50.45	20.88
Median	0.33	1.15	53.76	10.07
Std Dev	0.38	0.76	22.93	24.15
COV	0.85	0.63	0.45	1.16

1 in. = 25.4 mm

Similar tests were conducted to identify significant groups for the f_o data. Figure 1.5 is the final box and whisker plot, showing the two data groups: 258 Main St, plus 8 So. Beechcroft vs. all the data combined.

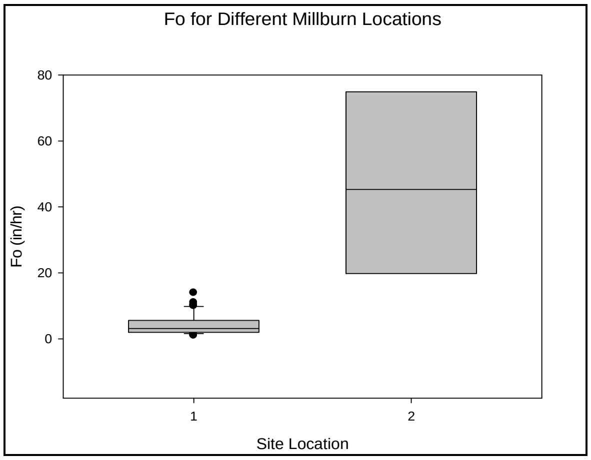

Figure 1.5 Box and whisker plot of f_o data showing two sets of data. (1 in./hr = 25.4 mm/hr)

Table 1.4 The results of the final Mann-Whitney Rank Sum test for f_o

Group	N	Missing	Median	25%	75%
Combined	43	0	3.12	1.94	5.63
258 Main & 8 So. Beechcroft	7	0	45.29	19.78	74.92

Mann-Whitney U Statistic= 0.000

T = 329.000; n (small) = 7; n (big) = 43; P = <0.001

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference: P = <0.001. Tables 1.5 and 1.6 summarize the values and test conditions for these two sets of data.

Table 1.5 f_o summary values and conditions for 258 Main St. and 8 So Beechdroft Rd.

	f_o (in./hr)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	7	6	7	7
Minimum	16.12	0.52	16.76	0.10
Maximum	75.14	1.71	54.77	1.94
Average	44.55	1.14	38.29	0.54
Median	45.29	1.28	41.29	0.32
Std Dev	23.74	0.45	14.98	0.65
COV	0.53	0.39	0.39	1.21

1 in. = 25.4 mm

Table 1.6 f_o summary values and conditions for 258 Main St. and 8 So Beechdroft Rd.

	f_o (in./hr)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	43	60	77	77
Minimum	1.01	0.22	6.51	0.00
Maximum	13.95	2.90	93.85	82.98
Average	4.34	1.20	51.28	21.93
Median	3.12	1.07	54.45	12.06
Std Dev	3.20	0.77	23.07	24.32
COV	0.74	0.64	0.45	1.11

1 in. = 25.4 mm

Similar tests were conducted to identify significant groups for the k data. Figure 1.6 is the final box and whisker plot, showing the two data groups: 258 Main St vs. all the other data combined.

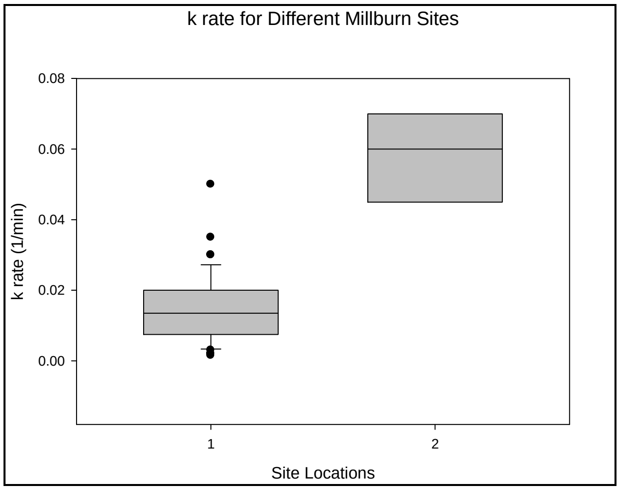

Figure 1.6 Box and whisker plot of k data showing two sets of data.

Table 1.7 The results of the final Mann-Whitney Rank Sum test for k

Group	N	Missing	Median	25%	75%
Combined	46	0	0.0135	0.0075	0.02
258 Main & 8 So. Beechcroft	3	0	0.06	0.045	0.07

Mann-Whitney U Statistic= 1.000

T = 143.000; n (small) = 3; n (big) = 46; P = 0.005

The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference, with P = 0.005. Tables 1.8 and 1.9 summarize the values and test conditions for these two sets of data.

Table 1.8 k summary values and conditions for 258 Main St. and 8 So Beechdroft Rd.

	k (1/min)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	3	3	3	3
Minimum	0.05	0.69	22.32	0.11
Maximum	0.07	1.34	54.77	0.67
Average	0.06	1.08	43.57	0.44
Median	0.06	1.22	53.62	0.53
Std Dev	0.01	0.35	18.41	0.29
COV	0.22	0.32	0.42	0.67

1 in. = 25.4 mm

Table 1.9 k summary values and conditions for 258 Main St. and 8 So Beechdroft Rd.

	k (1/min)	Rain Depth (in.)	Max. depth of water in dry well (in.)	Min. depth of water in dry well (in.)
Number	46	63	81	81
Minimum	0.002	0.22	6.51	0.00
Maximum	0.050	2.90	93.85	82.98
Average	0.014	1.20	50.45	20.88
Median	0.014	1.15	53.76	10.07
Std Dev	0.009	0.76	22.93	24.15
COV	0.666	0.63	0.45	1.16

1 in. = 25.4 mm

The Green-Ampt equation calculates cumulative infiltration assuming water flowing into a vertical soil profile. Figure 1.7 is an example comparison between fitted Horton and Green-Ampt equations for one of the events at a selected dry well, as well as statistical analysis and residual plots.

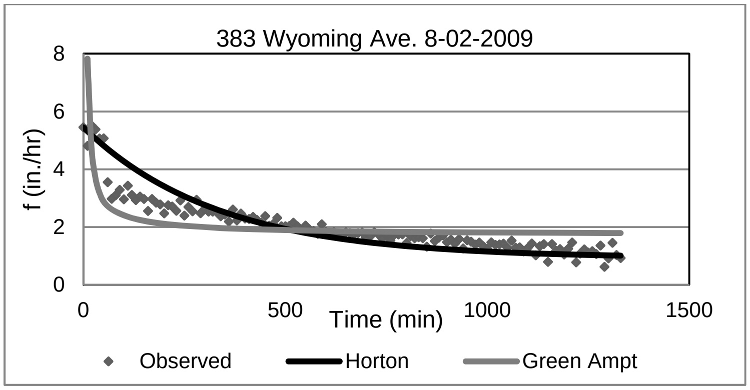

Figure 1.7 An example of fitted observed data to Horton equation and Green-Ampt equation (1 in. = 25.4 mm)

The results show that Horton equation usually had a better fit to the data compared to the Green-Ampt equation for the Millburn data. However, for some sites, the Green-Ampt equation provided a better fit. As noted previously, a linear relationship between ft and $(1/F_t)$ is needed to determine the Green-Ampt equation parameters. Figure 5-14 presents the linear regressions of ft vs $(1/F_t)$ for the monitored sites. The only visually acceptable linear regression is associated with the observations from the 258 Main St. site (the only location that had soils in the A group from the surface to about 1.1 m (3.5 ft) deep). In almost all cases, the linear relationship between ft vs $(1/F_t)$

is unacceptable (except for this one location), making the Horton equation a more suitable tool for calculating expected infiltration for the dry wells.

1.3.2 Factors Affecting Infiltration Rates

The analyses of the infiltration data resulted in several interesting conclusions. One of the first issues noted by the field personnel when installing the water level recorders and observing the dry wells over time was that some of the locations experienced periodic (or continuous) long-term standing water in the dry wells, indicating seasonal or permanent high water table conditions, or partially clogged dry wells.

Table 1.11 summarizes the dry well performance conditions observed during the monitoring program, including the length of monitoring, hydrograph behavior, and the presence of standing water (and the percentage of time when the dry well was dry).

In almost all cases, the general shapes of the recession limbs (water elevation drops with infiltration) are similar for all observations at the same site, including the hydrant tests. However, some changed with time, including several that indicated slower infiltration with more standing water conditions in the winter and spring. This may be due to SAR issues (sodium adsorption ratio) that results in dispersed clays from the high sodium content of snowmelt. Normally, snowmelt would not affect these units if only roof runoff is directed to the dry wells. However, if walkway or driveway runoff drains to dry wells, de-icing salts may be in the snowmelt, increasing the SAR and decreasing the infiltration rates.

Standing water was observed in the dry well at 87/89 Tennyson when sufficient time occurred to allow the water to reach a consistent minimum water level (about 0.9 m or 3 ft deep). It is expected that this site very likely has a shallow water table condition. The drainage rates were very slow, so the interevent periods were not sufficiently long to enable drainage to the stable water level until after about a two week dry period. The slow drainage rate may have been caused by saturated conditions associated with groundwater mounding. Several sites (260 Hartshorn, 7 Fox Hill, and 142 Fairfield) experienced periodic slowly draining conditions, mainly in the spring that could have been associated with SAR problems. The slow infiltration rates could be due to poor soils (with the clays resulting in SAR problems), or saturated soil conditions. The other sites all had rapid drainage rates that were consistent with time.

Table 1.11 Summary of infiltration conditions with time

Location	Start date of series	End date of series	# of dry well events	% of time dry well was dry	Consistent shape with time?	Standing water after events?	Other comments
11 Woodfield Dr.	Oct 11, 2009	Dec 20, 2009	1 hydrant 5 rains (1 small rain missing)	89%	Consistent shape with time	Quickly drained (within a day); No standing water at any time	15 hours total drainage time during hydrant test
15 Marion Dr.	June 17, 2010	August 6, 2010	1 hydrant 5 rains (2 small rains missing)	71%	Consistent shape with time	Several days to drain. ;No standing water at any time	4.5 days total drainage time during hydrant test
383 Wyoming Ave.	July 16, 2009	October 14, 2009	1 hydrant 6 rains (2 small rains missing)	81%	Consistent shape with time	Several days to drain if full; No standing water at any time	1 day total drainage time during hydrant test
258 Main St.	June 16, 2010	August 5, 2010	5 rains (2 smaller rains missing)	98%	Consistent shape with time	Very rapid drainage time; No standing water at any time	
260 Hartshorn	August 9, 2010	August 1, 2011	Many	10%	Consistent shape with time	Slow drainage time (about a week if full), but dry if given enough time between rains	Clogging or poor soils, not high water table. Possible SAR issues in the Winter and Spring, recovered by mid-summer.
2 Undercliff Rd	July 18, 2009	October 6, 2009	1 hydrant 3 rains	79%	Consistent shape with time	Several days to drain if full; No standing water at any time	10 days total drainage time during hydrant test
87/89 Tennyson	August 10, 2010	August 5, 2011	Many	0%	Consistent shape with time	Very slow drainage time (a couple of weeks); standing water and never dry during this period	Slow drainage may be due to saturated conditions, never reached stable low water level. If due to SAR, did not recover.
7 Fox Hill	August 7, 2010	March 23, 2011	Many	2%	Consistent shape with time	Slow drainage time (about a week or two if full), but dry if given enough time between rains	Clogging or poor soils especially in Spring, possibly SAR issues, not high water table

Location	**Start date of series**	**End date of series**	**# of dry well events**	**% of time dry well was dry**	**Consistent shape with time?**	**Standing water after events?**	**Other comments**
8 So. Beechcroft	July 19, 2009	September 27, 2009	1 hydrant 6 rains	71%	Consistent shape with time for rains, but hydrant test (at end of monitoring period at end of Sept) was very rapid	Quickly drained (within a day or two if full); No standing water at any time	3 hours total drainage time (half full) during hydrant test
142 Fairfield	August 10, 2010	March 4, 2011	Many	66%	Somewhat inconsistent shape with time	Quickly drained (within a day or two if full) to poorly drained (a week for moderate rains); Standing water during periods of large and frequent rains	Slowly drained conditions in Spring likely due to saturated conditions, or SAR. Not likely due to high water table
36 Farley Place	June 16, 2010	August 5, 2010	3 rains	97%	Consistent shape with time	Very rapid drainage time; No standing water at any time	

Another obvious factor affecting the observed infiltration rates was that one or two of the locations had significantly higher infiltration rates than the other sites (all having no standing water issues). These sites were the ones indicated as having the highest surface infiltration rate potentials (even though the infiltration rates of the dry wells were mostly affected by the subsurface soil conditions, which were mapped as being similar A and B conditions for all locations). It is therefore expected that these locations had better subsurface soil conditions compared to the other sites, even though mapped as being similar.

,The Township of Millburn infiltration rate characteristics were therefore separated into three conditions:

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

Table 1.12 compares the observed Horton equation coefficients for the sites having well-drained subsurface soils with equation coefficients that have been reported in the literature. The standing water data are not used in these calculations as most of the observations could not be successfully fitted to the Horton equation. The almost steady infiltration rates (but with substantial variation) were all very low for those conditions and and only represent the f_c values.

Table 1.12 Observed and Reported Horton Equation Coefficients

	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		

The very large observed f_o value (45 in./hr) for the A and B surface soil sites that are well drained is greater than any of the reported literature values, and only approaches the observations for the non-compacted sandy soil conditions (34 in./hr) observed by Pitt, et al. (1999). The subsurface soil conditions affecting the dry well infiltration rates are likely natural with little compaction. Also, the subsurface soils at that location are noted as being sandy loam (A) and stratified gravelly sand to sand to loamy sand (A). The other sites having smaller f_o rates (4.3 in./hr) are described as gravelly sandy loam (A) and fine sandy loam (B) and are similar to many of the reported literature values for sandy soils, with some compaction.

The large f_c value (5.6 in./hr) observed for the well-drained A and B surface soil location is bracketed by the non-compacted clayey and sandy soil conditions (3 and 15 in./hr) reported by Pitt, et al. (1999), but is substantially larger than the other reported values. The f_c value observed for the well-drained C and D surface soil site (0.45 in./hr) is similar to the other reported values (0.5 to 1.0 in./hr). The k first-order rate coefficient values (0.01 and 0.06 1/min) are similar, but on the low side, of the reported values (0.04 to 0.11 1/min).

In order to most accurately design dry well installations in an area, actual site observations of the expected infiltration rates should be used instead of general literature values. This is especially true for surface infiltration devices (such as rain gardens), where compaction due to construction activities and general urban use will have a much greater effect than on the deeper subsurface soils. Also, all of the sites in this study had improved infiltration characteristics with depth compared to expected surface conditions; in other cases, this may not be true. Criteria based only on surface soil conditions are likely not good predictors of deeper dry well performance. Luckily, county soil surveys do have some subsurface soil information that was found to be generally accurate during this study. Unfortunately, shallow water table conditions are not well known for the area and that characteristic can have a significant detrimental effect on observed dry well performance.

1.3.3 Water Quality Observations

The samples were analyzed in laboratories of the University of Alabama for bacteria (total coliforms and *E. coli*), 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).

A number of complementary statistical analyses of the water quality data were conducted using MINITAB and MS-Excel software, including: log-normal probability plots, Anderson-Darling (AD) p test for normality, group box plots, paired line plots, time series plots, and Mann-Whitney comparison tests (or the paired sign test for metals due to large fractions of non-detected observations).

Table 1.13 shows the output obtained using MINITAB for nonparametric Mann-Whitney comparisons between paired data. Except for the bacteria and COD results for the cistern site, as noted previously, all paired sample sets did not indicate significant differences for these numbers of samples at the 0.05 level for the numbers of sample pairs available.

Table 1.13 Summary of Mann-Whitney tests for paired data

Parameter		**79 Inflow vs. 79 Cistern**	**135 Shallow vs. 135 Deep**	**18 Shallow vs. 18 Deep**	**139 Shallow vs. 139 Deep**
Total Coliforms	p-value	0.03	0.40	0.16	0.72
	Significant Difference Observes? (at level of 0.05)	Yes (but cistern median values were larger than the inflow median values)	No	No	No
E. coli	p-value	0.05	0.60	0.69	1
	Significant Difference Observes? (at level of 0.05)	Yes (cistern median values significantly less than the inflow median values)	No	No	No
Total Nitrogen as N	p-value	0.86	0.50	0.42	0.64
	Significant Difference Observes? (at level of 0.05)	No	No	No	No
NO_3 plus NO_2-N	p-value	0.14	0.24	0.15	0.77
	Significant Difference Observes? (at level of 0.05)	No	No	No	No
Total Phosphorus as P	p-value	0.77	0.94	0.10	0.27
	Significant Difference Observes? (at level of 0.05)	No	No	No	No
COD	p-value	0.04	0.14	0.40	0.83
	Significant Difference Observes? (at level of 0.05)	Yes (cistern median values significantly less than the inflow median values)	No	No	No

Table 1.14 lists the results for the paired sign test (used because of numerous non-detected values) for lead, copper and zinc observations for the cistern and dry well samples. No statistically significant differences were

seen between the sample sets for the heavy metals for the numbers of samples available.

Table 1.14 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	p-value	> 0.06	> 0.06	0.18	> 0.06
	Significant Difference in Medians?	No	No	No	No
Copper	p-value	0.13	*	>0.06	*
	Significant Difference in Medians?	No	*	No	*
Zinc	p-value	0.45	0.45	>0.06	>0.06
	Significant Difference in Medians?	No	No	No	No

* all non-detected

Statistical analyses indicated that the differences in water quality between the shallow and the deeper samples were not significant for the number of sample pairs available (p-values were > 0.05). However, significant differences were found ($p < 0.05$) between the quality of inflow samples and cistern samples for total coliforms (possible re-growth), *E. coli*, and COD (concentration reductions). These findings indicate that the dry wells do not significantly change the water quality for most of the stormwater constituents. If the influent water quality is of good quality, the dry wells can be a safe disposal method for stormwater quality. However, most of the bacteria and lead concentrations exceeded the groundwater disposal criteria for New Jersey and may require treatment, if the aquifer is critical.

1.4 Conclusions

Dry wells may be a preferred option in cases that are allowed by the New Jersey dry well disposal regulations for stormwater which limits their use to areas having excellent soils (HSG A or B), where the groundwater table is below the dry well system (to prevent standing water in the dry wells and very slow infiltration), and to only receive roof runoff water (generally the best quality runoff from a site and not contaminated with deicing salts). However, the beneficial uses of roof runoff should be the preferred option, and in many cases may be less costly, especially considering increasing water utility rates and the desire to conserve highly treated domestic water supplies. Shallow groundwater recharge may be an important objective for an area, but “over” irrigation (beyond the plants evapotranspiration, ET, deficit needs, but less than would produce direct runoff) would also contribute to that objective, at the same time as conserving water and offering better groundwater protection.

Figure 1.8 is a map showing the general infiltration rate conditions for Millburn, as monitored during this project. Most of the monitored dry wells were along a ridge between the two main drainages of the township, with no obvious pattern of high water conditions, except that the high standing water dry wells were located along a line to the southwest along the ridge and are located fairly close to headwaters of streams (high water tables were noted in areas with nearby streams, but that was assumed to be in the larger stream valleys and not at the headwaters). The sites that had high standing water long after the events ended had substantially reduced infiltration rates. In the analyses, these rates were considered to be the constant (final) rates observed, with no initial rate data or first-order decay Horton coefficients used (relatively constant, but very low infiltration rates). Three of the sites had severely degraded infiltration conditions (260 Hartshorn, 87/89 Tennyson, and 7 Fox Hill). These sites all received runoff from the entire property or from multiple impervious areas (and are 1 to 5 years old). It is not known if the source water or groundwater conditions affected the drainage conditions at these sites. Dry wells receiving runoff from all impervious areas would have a greater silt load and likely clog prematurely compared to sites only receiving roof runoff.

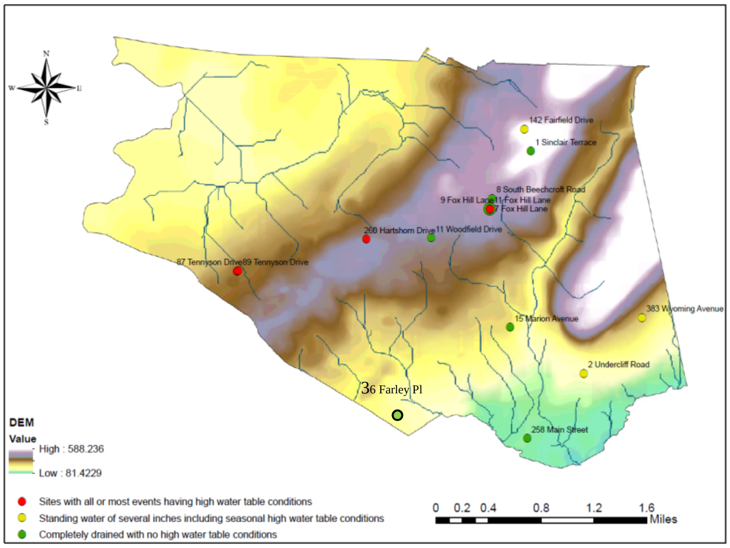

Figure 1.8 Township map showing locations having varying standing water conditions in monitored dry wells.

Even sites having surface C and D soils (not acceptable infiltration sites according to the New Jersey dry well standards) had much better subsurface conditions where the dry wells were located than the surface conditions. The infiltration rates for these conditions were less than for the excellent areas having A and B surface soils, but all met the infiltration rate criteria of the state guidelines.

Table 1.15 lists the most stringent regulatory levels for groundwater contaminants derived from N.J.A.C. 7:9C (2010), along with the range of observed concentrations for each constituent during these tests. The microbiological and lead concentrations frequently exceeded the groundwater disposal criteria.

Table 1.15 Groundwater Quality Criteria for the State of New Jersey Compared to Observed Water Quality from Dry Wells

Constituent	**Groundwater Quality Criterion**[1]	**Observed Range** [1]	**Fraction of samples that exceed the criteria**
Microbiological criteria[2]	Standards promulgated in the Safe Drinking Water Act Regulations (N.J.A.C. 7:10-1 et seq.)[3]	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	n/a	0.02 to 1.36	n/a
COD	n/a	5.0 to 148	n/a
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

[1] Ground water quality criteria and observed range are expressed as mg/L unless otherwise noted.

[2] Pursuant to prevailing Safe Drinking Water Act Regulations any positive result for fecal coliform is in violation of the MCL and is therefore an exceedance of the groundwater quality criteria.

[3] 50 MPN/100 mL

Reference evapotranspiration (ET) rates for the Millburn area range from about 0.4 mm/day (0.015 in./day) during January to about 4 mm/hr (0.16 in./hr) during May through July. The period of maximum ET also corresponds to the period of maximum rainfall in the area, reducing the need for irrigation (and also the sizes of long-term water storage tanks). Therefore, the beneficial use of roof runoff for irrigation is limited if it is used only to meet the irrigation demand. However, irrigation can also be used as a stormwater management option with excess water being used to recharge the shallow groundwater and to meet the increased moisture needs of some heavily watered lawns (such as common Kentucky Bluegrass).

Rain gardens are another viable alternative for stormwater management in the Millburn area, especially as they provide some groundwater quality protection and can be incorporated into the landscaping plan of the site. They likely require additional maintenance; similar to any garden, but they can be placed to receive runoff from several of the source areas on a site, increasing the overall stormwater management level. They have even been incorporated along roads, as curb-cut biofilters, resulting in significant overall runoff volume reductions (but with special care to prevent pre-mature clogging, reduced salt discharges, and appropriately sized to handle the large flow volumes).

Alternative stormwater options should be used when dry well use should be restricted, such as with the following conditions:

- poor infiltration capacity of subsurface soil layers;
- concerns about premature clogging or other failures due to sediment; discharges or snowmelt discharges to dry wells;
- seasonal or permanent high water tables; and,
- concerns about groundwater contamination potential.

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