

Nine Mile Run Watershed Study: Application of Rain Barrels as a Stormwater Management Technique

**Report to
Nine Mile Run Watershed Association
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1. INTRODUCTION

The Nine Mile Run Watershed Association (NMRWA) is concerned about the deterioration of the quality of water in Nine Mile Run (NMR) and the impact on the watershed communities. The NMRWA seeks to mitigate the negative impacts through raising awareness in the community and implementing programs to provide more responsible management of this natural resource.

A critical water quality problem in NMR is sewage inputs from combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) during storm events. The NMR corridor serves as a route for sewers from four communities (Pittsburgh, Wilkinsburg, Edgewood, Swissvale), and has long been impacted by sewage overflows. Rapid runoff of stormwater in the NMR watershed exacerbates the overflow problem, leading to overflows even during rainfall events involving small amounts of precipitation.

One approach taken by the NMRWA to help reduce the flow from stormwater into the sewer system has been a program to install rain barrels on residential structures. Rain barrels are designed to capture runoff from residential roofs through downspouts. Since rain barrels collect runoff during a storm, less runoff travels to the sewer and there is a lower flow in the sewer system. This can have a direct result on reducing the amount of untreated sewage entering the stream.

In 2004, NMRWA installed over 500 rain barrels throughout the watershed as part of a program designed to help mitigate runoff as well as to engage and educate residents in the issue of runoff in the watershed. The 2004 project was successful in raising awareness among residents about impacts that individuals can have on the watershed in which they live. More information about the 2004 program is available at NMRWA (www.ninemilerun.org).

A modeling study performed by CDM Inc (2005) for NMRWA indicated that many more rain barrels would have to be installed in the watershed to have a measurable impact on reducing the rate and volume of stormwater runoff. No data exist to quantify the extent of the flow reduction.

In 2006 NMRWA initiated planning to obtain quantitative information about the effect of residentially installed rain barrels on runoff in the sewer system via a dense installation of rain barrels. This report describes the results of that planning effort. Candidate sites for a dense installation of rain barrels in the NMR watershed were identified and evaluated, and the best potential sites for implementation were selected. The dense installation of rain barrels will aim to provide an understanding of the impact of rain barrels by collecting flow data from a small residential portion of the watershed.

If the rain barrel study can show that a significant reduction of runoff flow in the sewer can be achieved with the use of rain barrels, then the NMRWA will have a

basis for considering the rain barrel to be a practical storm water management tool or best management practice (BMP). There are several different BMPs that are currently in use. Pervious pavement, storm water detention and swales are some examples. However, not all BMPs are appropriate in all circumstances. This study will determine whether rain barrels can be an effective BMP in residential communities. If so, implementation of rain barrels can be expanded throughout the residential areas of the NMR watershed and adopted by watersheds in other regions.

2. CANDIDATE SITES FOR THE RAIN BARREL STUDY

The goal of the rain barrel study is to raise awareness in the community about watershed issues and also to document and quantify the impact that rainwater storage can have on reduced stormwater runoff rates and volumes during a rain event. The NMRWA values the participation of community members, upon whom the success of this study is dependent. A contained residential area (study-area) will be selected for the study and provided with rain barrels for each residential building. The residents have the opportunity to participate in the study by accepting the barrels and if they choose, by volunteering to monitor their barrel(s).

A rain barrel impact study in part of the NMR watershed is conducted through the collection of pre-rain-barrel sewer flow information (baseline data) to use for comparison. Baseline sewer flow data has been collected at various locations in the NMR sewershed in 2001-2002 for purposes of sewer system assessment. The engineering firm of Lennon, Smith and Souleret (LSSE) has provided NMRWA with the sewer flow data gathered in 2001-2002. The locations where the sewer flow data were obtained were evaluated as potential candidate sites for the dense rain barrel study. The 2001-2002 monitoring was conducted at several dozen locations throughout the NMR sewershed (indicated by dots in Figure 1). For each of the locations where flow in the sewer was monitored, there is a corresponding micro-sewershed, which contributes flow to that location. The micro-sewershed is composed of the buildings that are connected to the sewer at any point above the location of the flow monitor.

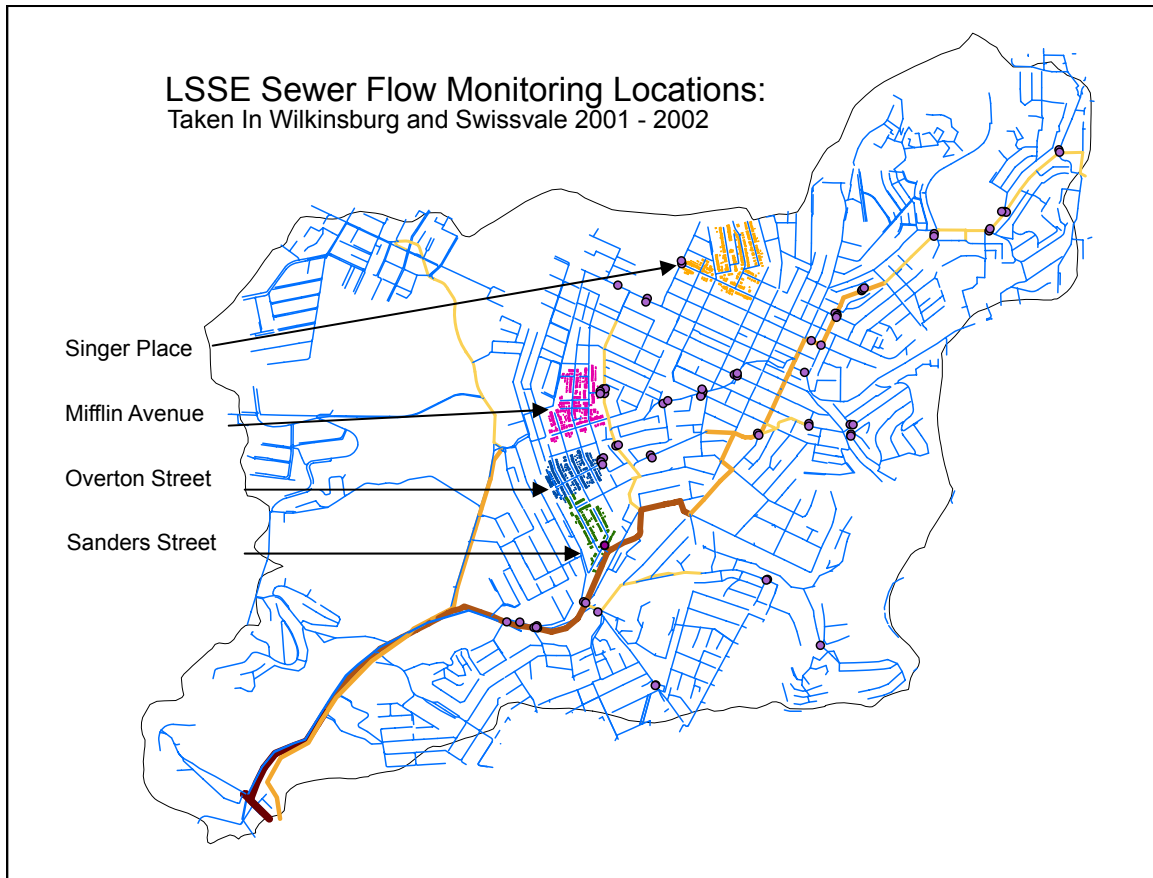


Figure 1 – Map of NMR watershed showing sewer lines. Dots represent locations for which sewer flow data was gathered. The four colored areas, indicated by name and by arrow, show the drainage areas (micro-sewersheds) that contribute to the four corresponding flow monitor locations.

The locations monitored by LSSE in 2001-2002 were examined in order to determine the residential areas where the rain barrels should be placed. Each location has an associated micro-sewershed, which is simply the area that contributes flow to that point in the sewer where the flow monitor is placed (Figure 1). The size of the area and the number of structures in the micro-sewershed are important factors in determining the locations suitability for the study. Too few structures in the study-area (micro-sewershed) can result in a sewer flow that is too small to provide accurate data, whereas too many structures would be beyond the scope of the study. The target size-range for the study-area is approximately 150 to 500 residences. Criteria were developed to help choose study-areas that are most likely to demonstrate the positive impact that rain barrels can have. These criteria are described in Table 1. Using these criteria, the sewershed areas associated with the various sewer flow monitoring points of 2001-2002 were assessed.

Table 1 - Criteria used as a basis for identifying useable study-areas.

<p><u>Residential land use</u> – Residential buildings are the primary targets for rain barrel installation. Other types of buildings such as commercial may or may not be included in a future study.</p>
<p><u>Accessibility to monitoring location</u> – The study-area will be a small sewershed, defined by its sewer network. The sewer network has several reaches of pipe, which flow to a single point, like branches to a tree trunk. It is critical that this point is accessible so that a monitoring device can be introduced. Areas considered in this study have already proven conformity to this criterion.</p>
<p><u>Density of residences</u> – Maximizing the total residential roof area also maximizes the amount of runoff that can be collected in the study-area. ‘Maximize’ does not refer to the roof area of a single structure but rather to the ratio of total roof area to total land area.</p>
<p><u>Existence of rain barrels in sub-watershed</u> - Areas that have already been seeded with rain barrels will provide a ‘head-start’ for the next phase implementation.</p>
<p><u>Community Involvement & Visibility</u> - Neighborhoods demonstrating interest in watershed improvement are potentially valuable resources. Visibility to community members increases public education to the health of the watershed and stormwater management practices.</p>

Critical spatial data were shared with NMRWA by 3 Rivers Wet Weather Demonstration Project (3RWWDP), LandBase Systems and the Carnegie Mellon STUDIO for Creative Inquiry. Maps show the approximate locations of sewer lines below ground (Figure 2). This feature was especially useful because buildings were included in a particular micro-sewershed based on the sewer lines to which runoff (from the buildings roof and surround land surface area) drained. Each micro-sewershed that was identified includes all of the residential structures that drain to a particular point in the sewer. This point is a strategic location through which flow from the entire study-area passes.

Geographic information system (GIS) maps used spatial data to identify those micro-sewersheds that contribute flow to the given monitoring locations in the NMR sewershed. Given the location of the monitoring device in the sewer, the boundaries of the candidate study-area are defined (see Figure 2). The GIS maps display the sewer line and the building footprints for the micro-sewershed for each monitoring location. Of all of the monitoring locations from the 2001-2002 study, many were eliminated as candidates because of the high number of buildings in the micro-sewershed and the high flow measured at the monitoring location. Other monitoring locations were not suitable because the small number of buildings included in the micro-sewershed produced a low flow that was not easily detected by the monitoring device. Some of the remaining micro-sewersheds that contained large commercial buildings or wide-open spaces such as fields or parking lots were also considered to be unsuitable as study-areas. The elimination of these candidate micro-sewersheds was based on a visual assessment of their conformity to the criteria in Table 1. After removing from consideration those micro-sewersheds that were apparently not suitable, four micro-sewersheds (study-areas) remained. These four study-areas are shown and labeled in Figure 1.



Figure 2 - An example of a micro-sewershed (Overton Street study-area) composed of sewer line in red and contributing residences in yellow.

3. ANALYSIS OF CANDIDATE SITES

For this study, a runoff volume reduction of 10% was considered the threshold showing that a significant impact was provided by the rain barrels. To achieve this, the barrels must capture ten percent of the runoff in the study-area. This could potentially be a large amount of runoff in absolute volume. A graphical representation of the study-area in GIS is used to estimate the expected runoff volume. GIS maps include the building footprints, sewer lines, and pervious and impervious surfaces. In the example shown in Figure 2, the pervious surface is light green in color and the impervious surface is dark blue. If all of the yellow-colored residences had a rain barrel connection there could be a significant reduction in runoff within the pipe.

There are several methods that can be used to estimate the amount of runoff expected for a given storm (Haestad, 2003; p116). The one used in this study was the NRCS (SCS) Curve Number Method. The result of the calculation was used to estimate the number of rain barrels that would be required to achieve a ten percent reduction in runoff volume.

Following is a step-by-step example of how the SCS method was applied.

Step 1. Determine the maximum runoff retention.

The curve number is a parameter that is dependent on the soil type and ground cover (Haestad, 2003; p126). A curve number of 100 would describe a surface that is completely impenetrable to and cannot hold water, imagine a drop of water rolling off a waxed surface. Such a surface would have zero capacity to retain runoff; there would be no infiltration or depression storage (such as puddles). Practically speaking, all curve numbers are less than 100. Although, if you were to walk around in the study-area the curve number would vary widely from surface to surface, a single curve number (85) is chosen for the overall watershed (Khan, p 97). As the curve number decreases, the ability of the surface to retain water increases. This is a direct relationship represented as:

$$S = \frac{1000}{CN} - 10 \quad (1)$$

CN = runoff curve number
 S = maximum possible runoff retention (inches)

The parameter (S) is important in the SCS method, allowing the calculation of the amount of rain that contributes to runoff.

Step 2. Determine the effective precipitation depth.

The amount of rain that contributes to runoff is called the effective precipitation depth (P_e) (Haestad, p 119).

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (2)$$

P = total precipitation depth (inches)

The value used for P was taken from the study of the NMR watershed by CDM (2005), where it is stated: “approximately 10 percent of the storms in the historic record deposited about 1 inch or more of precipitation.” Therefore, a precipitation depth of P = 1.0 inch, would represent ninety percent of the storms on record. Ninety percent of storms is sufficient because this report does not intend to show that rain barrels are effective in managing runoff from more severe storms (about seven per year) but rather those that occur on a more regular basis (CDM, 2005; p 6).

Step 3. Estimate runoff volume.

Referring again to Figure 2 as an example, the SCS method was applied to estimate runoff for the Overton Street study-area in a one-inch rainfall. The SCS

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method yields an effective precipitation depth, (P_e), of 0.17 inches. The Overton Street study-area covers 22 acres (A), producing 104,100 gallons of runoff (V_r), as calculated from the following equation (Haestad, 2003; p117).

$$V_r(\text{gal}) = P * \frac{1\text{ft}}{12\text{in}} * A * \frac{325900\text{gal}}{\text{acre} - \text{feet}} \quad (3)$$

Step 4. Estimate the number of rain barrels required for 10 percent runoff volume retention.

The number of rain barrels needed to contain ten percent of the runoff was determined by dividing the total volume of runoff, V_r , by the capacity of a single barrel (133 gal). For the Overton Street study-area, it was found that 78 rain barrels would hold ten percent of the runoff from the design storm. A summary of these findings for the four study-areas is shown in Table 2.

Table 2 – Summary of runoff analyses for study-areas using SCS Method.

Study-area Name	Number of Buildings	Number of Acres in Study-area	Gallons of Runoff	Barrels Required to Hold Ten Percent
Singer Pl	253	35.2	166095	125
Overton St	205	22.1	104101	78
Mifflin Ave	260	31.2	147149	111
Sanders St	173	18.7	88179	66

The results of the candidate site analyses in Table 2 are promising, suggesting that the mark of 10% reduction in stormwater runoff can be reached with reasonable number of rain barrels. Table 2 indicates that the number of barrels is a good deal less than the number of buildings in the area. If the participation rate is high within the community and barrels are installed on most of the homes, it can be expected to result in a measurable reduction of runoff.

The results given in Table 2 for the number of barrels required assume that ten percent of the runoff finds its way into the barrels. However, the residential rooftop is the means by which runoff travels into the barrel. Therefore, the residential rooftop area for a particular candidate site can be considered the 'collection area' or the area by which runoff can be collected. It is important that this collection area comprise a certain amount of the total study-area and the more the better. If the residential roof area comprised less than ten percent of the total study-area then it would be impossible to collect ten percent of the runoff. The proportion of collection area provides an upper limit of the proportion of total runoff that can be collected. Furthermore, if residential roofs represented exactly ten percent of the total study-area, this too would be insufficient because it is not feasible to connect 100% of roof area to rain barrels.

The proportion of collection area to total study-area is therefore an important

parameter in evaluating the candidate sites. This is the primary measure for the ‘density of residences’ criterion in Table 1. The proportion, which is expressed as a ratio R, is in general terms the percentage of roof area to total area. However, to be more precise, the areas are weighted according their surface type. The weighting is used because a square foot of roof produces more runoff than a square foot of lawn. C_1 and C_2 are the weighting factors, which allow the impervious surfaces to be better represented for their runoff contribution (Haestad, 2003; p142). Note that below two different roof areas are used. $Roof_1$ represents the collection area or those roofs that could prospectively be connected to rain barrels. $Roof_2$ includes $Roof_1$ as well as all other roofs, which would not be considered for rain barrels (such as sheds or commercial buildings). The ratios, R, for the study-areas are shown in Table 3.

$$R = \frac{C_1 * Roof_1}{C_2 * Perv + C_1(Roof_2 + IMperv)} \quad (4)$$

$$C_1 = 0.75$$

$$C_2 = 0.2$$

$Roof_1$ = acres covered by residential roofs

$Roof_2$ = acres covered by all of roofs

Perv = acres of pervious area

IMperv = acres of impervious area

Table 3 – Ratio of collection roof area to total surface area for each study location.

Study-area Name	Pervious	Impervious	Roof	Ratio, R
	(Acres)			
Singer Pl	23.0	5.6	6.6	0.332
Overton St	14.3	3.8	4.0	0.288
Mifflin Ave	19.6	5.9	5.7	0.300
Sanders St	12.6	3.1	3.0	0.277

The ratio R can be used as an approximation of the possible proportion of total runoff that is from residential roofs. Consequently, a value of $R > 0.1$ is necessary to attempt to capture 10% of runoff. Since the values in Table 3 are well above 0.1, it is a realistic prospect for each of the candidate study locations to be able to connect sufficient roof area to rain barrels and collect the target amount of runoff.

4. RUNOFF DATA COLLECTION PLANS

The runoff from the study location chosen for dense rain barrel installation will be monitored by installation of a flow-monitoring device in the sewer that drains the micro-sewershed. The device will be installed at the same location monitored in

the 2001-2002 study. It is hypothesized that runoff flow inside the sewer pipe will be reduced after the rain barrels have been installed. This hypothesis will be tested by a comparison of the flow data collected before and after the installation of the barrels.

To compare the two sets of flow data, before and after rain barrel installation, a few assumptions are made. The conditions within the pipe (i.e. debris) and the operation of the flow monitor will be assumed to be the same for both sets. Further, it will be assumed that there were no significant changes to the land use of the study-area in the period between the collections of the two data sets. For example, if an open field present in 2001-2002 was converted to a parking lot after the initial monitoring period, the runoff for this area would be different than it had been before. Additionally, the precipitation event for which the flow data was collected must be very similar for both data sets. This means that the storm duration and overall rainfall amounts should be very similar between the two.

A supplementary method of evaluating the impact of the barrels on sewer flow will also be employed. Volunteer residents in the study groups will check the volume of runoff collected in the barrel immediately following a particular storm. Several volume measurements from different rain barrels will provide a direct estimate of the runoff collected throughout the study-area after each rainfall.

Many factors will need to be properly coordinated in order to obtain useful results. Most importantly, sufficient participation by the residents in the study-area will be needed. In addition, it will be important for NMRWA to ensure the proper installation of the rain barrels as well as provide the owners with proper maintenance information and support. Also, the ability to gather good flow data within the sewer depends on some degree of wet weather. If the flow-monitoring period is only a few weeks, the likelihood of experiencing storms comparable to those during the one-year baseline monitoring in 2001-2002 will be reduced.

5. SUMMARY

The measured flow data that was taken both before and after the rain barrel installations will be compared. These two sets of flow data will have been gathered during very similar rain events. There are, however, variables that can blur the ability to compare the two flows. Conditions on the surface as well as in the sewer are assumed to stay the same over the several years between the two monitoring periods. Though two rain events may be similar, they will not be the same. This is significant because the features of the runoff flow are as unique as the rain event.

This study provides guidelines of important features of the selected micro-sewersheds to be used for the rain-barrel runoff mitigation study. Important qualities of the study-area, included in Table 1, require that it be densely

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populated with residential buildings in order to maximize the area that can be drained to rain barrels. After reviewing several possible locations for which flow data had already been collected, four study-areas, identified in Table 2, were chosen. At these four locations, the NMRWA will reach out to educate and engage community members to participate. The analysis presented in this report provides the amount of residential roof area in each micro-sewershed and the number of rain barrels that are expected to reduce runoff volume by ten percent. These guidelines serve as a minimum mark, which should be exceeded, if possible, to emphasize the utility of rain barrels as a BMP in residential communities.

After resident volunteers have installed rain barrels on their homes, the positive impact of this program is greatly increased. However, it is not until the data has been collected and analyzed that we will know the effect. The project will provide a better understanding of the impact of rain barrels, which could be useful for other urban areas as well. Urban areas that are interested in implementing storm water management practices will be able to use this study to help them decide if rain barrels are a viable option. The NMR watershed area will benefit in several ways from the success of this study. If the study shows that rain barrels can have a significant impact on runoff entering the sewers, the rain barrels will be looked at by the residents and municipalities as an effective tool to improve water quality. An expansion of this project throughout the watershed could potentially reduce the CSOs and SSOs that introduce raw sewage into the NMR stream.

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