FHWA-NJ-2014-011

Stormwater System Monitoring and Evaluation - Implementation

FINAL REPORT

December 2013

Submitted by

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In cooperation with

New Jersey
Department of Transportation
Bureau of Research
And
U.S. Department of Transportation
Federal Highway Administration

Disclaimer Statement

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2014-011	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Stormwater System Monitoring and Evaluation - Implementation		5. Report Date December 2013 6. Performing Organization Code CAIT/Rutgers
7. Author(s) Guo, Qizhong (George) and Jung Hoon Kim		8. Performing Organization Report No.
9. Performing Organization Name and Address Rutgers, The State University of New Jersey Department of Civil & Environmental Engineering and Center for Advanced Infrastructure & Transportation (CAIT) 96 Frelinghuysen Road Piscataway, NJ 08854		10. Work Unit No. 11. Contract or Grant No.
12. Sponsoring Agency Name and Address New Jersey Department of Transportation CN 600 Trenton, NJ 08625	Federal Highway Administration U.S. Department of Transportation Washington, D.C. 20590	13. Type of Report and Period Covered 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

To improve the quality of highway runoff and meet the new stormwater management requirements, the New Jersey Department of Transportation (NJDOT) has installed numerous prefabricated stormwater treatment systems throughout the state produced by a range of manufacturers. The use of such systems, known as Manufactured Treatment Devices (MTDs), is expected to continue in the foreseeable future. As the responsible party for the maintenance of these MTDs, NJDOT is interested in determining optimum maintenance intervals and expected maintenance costs for the range of MTDs utilized by the Department.

In the previous research project, twelve stormwater manufactured treatment devices (MTDs) along New Jersey highways were selected for monitoring over one year. In this implementation phase of the project, the twelve devices were monitored for an additional three years or till they reached the maximum allowable sediment storage capacity.

Depths of the sediment accumulated on bottom of the devices were measured every three months. The time interval for required cleanout was determined by comparing the measured sediment depth and the maximum allowable depth. Information on the devices as well as data on the drainage area were also collected. Through the statistical analysis, it was found that the cleanout interval was correlated well with the number of vehicles on the road(s) and the impervious land surface area. This relationship can be used to project the MTD cleanout interval, prepare for the maintenance budget, and optimize the maintenance schedule.

17. Key Words Stormwater, Maintenance, Stormwater and Roadways, MTD	18. Distribution Statement		
19. Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 23	22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The authors wish to thank various NJDOT staff members who had supported this project, particularly Edward S. Kondrath for project management. We would also like to thank CAIT staff members for their office and accounting support.

The authors wish to make a special acknowledgement to our NJDOT customers, without whom this project would not have come to fruition.

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EXECUTIVE SUMMARY

To improve the quality of highway runoff and meet the new stormwater management requirements, the New Jersey Department of Transportation (NJDOT) has installed numerous prefabricated stormwater treatment systems throughout the state produced by a range of manufacturers. The use of such systems, known as Manufactured Treatment Devices (MTDs), is expected to continue in the foreseeable future. As the responsible party for the maintenance of these MTDs, NJDOT is interested in determining optimum maintenance intervals and expected maintenance costs for the range of MTDs utilized by the Department.

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INTRODUCTION

To improve the quality of highway runoff and meet the new stormwater management requirements, the New Jersey Department of Transportation (NJDOT) has installed numerous prefabricated stormwater treatment systems throughout the State produced by a range of manufacturers. The use of such systems, known as Manufactured Treatment Devices (MTDs), is expected to continue in the foreseeable future. As the responsible party for the maintenance of these MTDs, NJDOT is interested in determining optimum maintenance intervals and expected maintenance costs for the range of MTDs utilized by the Department.

In the previous research project (Guo and Kim, 2010), to be consistent, all the monitored twelve devices are of the same type Vortechs (Figure 1), a hydrodynamic separator (HDS). The twelve (12) treatment devices located across the State (Figure 2 and Table 1) were selected for monitoring and evaluation. The completed one-year field monitoring indicates that up to half a foot (0.5 ft) depth of sediment was trapped by the devices. The devices need to be cleaned out after the sediment accumulates to two feet (2 ft) of depth. A linear extrapolation of the one-year depth leads to an estimate of maintenance interval of four years. The extrapolated/estimated maintenance interval of four years is far less than one year generally suggested by the device manufacturers. This would lead to a significant savings in maintenance costs for NJDOT. Due to the potential for significant savings and the possibly non-linear sediment accumulation, the extrapolated/estimated maintenance interval should be confirmed by the actually measured maintenance interval.

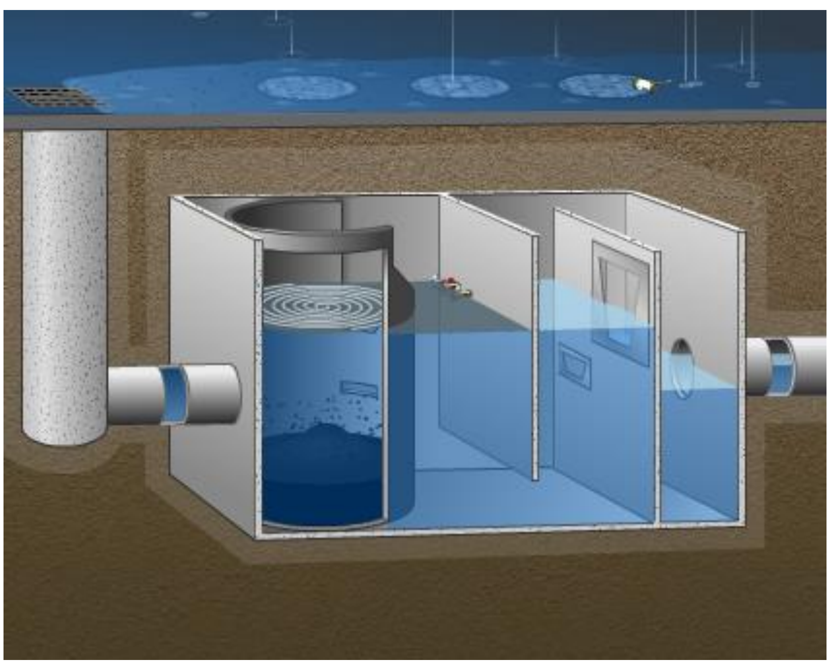

Figure 1. Vortechs stormwater treatment system (Source: http://www.contech-cpi.com/stormwater/13)

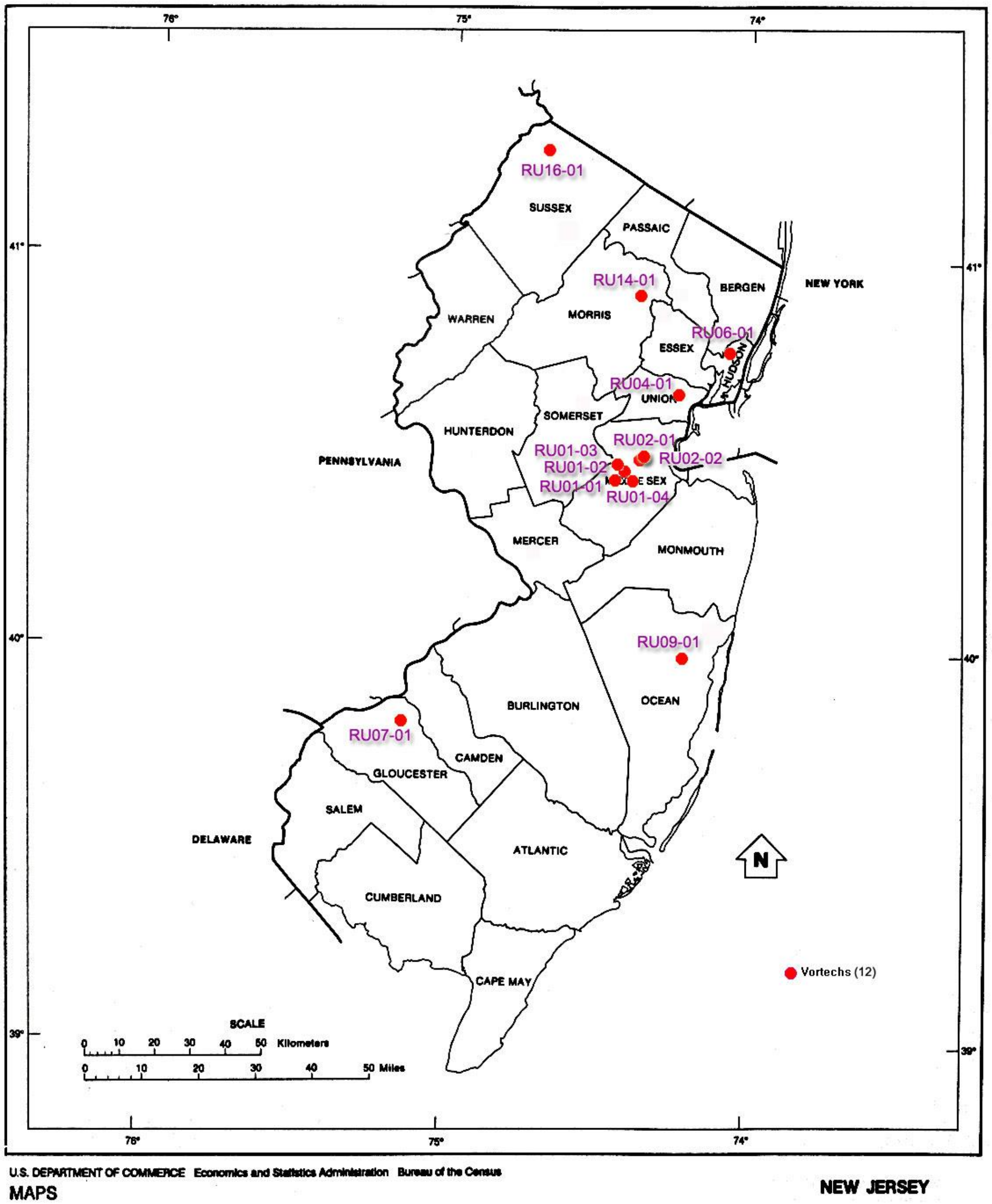

Figure 2. Locations of 12 Vortechs® installed at 8 NJDOT project sites that were selected for extensive monitoring

Table 1. Twelve (12) Vortechs Devices for Continual Monitoring

Site ID	Municipality	County	Location
RU01-01	Piscataway	Middlesex	Rt. 18 Extension along Landing Lane
RU01-02	Piscataway	Middlesex	Rt. 18 Extension along River Road
RU01-03	Piscataway	Middlesex	Rt. 18 Extension along Campus Road
RU01-04	Piscataway	Middlesex	Rt. 18 Extension along River Road
RU02-01	Edison	Middlesex	Evergreen Road and State Highway 27
RU02-02	Edison	Middlesex	Evergreen Road and State Highway 27
RU04-02	Elizabeth	Union	Pearl Street & Grove Street
RU06-01	North Bergen	Hudson	36th Street
RU07-01	Deptford	Gloucester	Rt. 47 near Cattle Road
RU09-01	Lakewood	Ocean	Rt. 9 near Lake Carasaljo
RU14-01	Parsippany	Morris	Rt. 46 & New Road
RU16-01	Frankford	Sussex	Rt.15 & US 206

Thus, for this implementation phase of the project, it was proposed to continue monitoring and evaluation of the same twelve (12) stormwater treatment devices till they reach the maximum storage capacity. The continuation project was aimed to confirm the maintenance interval extrapolated from the previous one-year monitoring program.

Assurance of the extrapolated maintenance interval would reduce NJDOT's maintenance costs to one fourth of that generally suggested by the device manufacturers and will assist NJDOT in implementing the previous research results with a higher level of confidence.

MEASUREMENTS OF BOTTOM SEDIMENT ACCUMULATION

Measurement Procedure

The sediment accumulation depth over the observation period was used as the lead indicator for the time interval between HDS cleanouts. The sediment depths were measured subsequently from the clean state. The depths were measured at a pre-determined time interval, every two months from December 2007 to July 2009 and every three months thereafter.

The sediment accumulation depth was measured using a stadia rod. Personnel trained in safety procedures including confined space entry manually opened the manhole cover atop the swirl chamber of each HDS. Pictures of oil and floatables were taken and proportion of covered area was calculated.

Measured Results on Sediment Accumulation

Monitoring of the twelve (12) selected devices started between the end of 2007 and the first half of 2008 and lasted about one and one half years during the previous research project. The second phase (this implementation phase) of the research project started in November 2009 and lasted three years. The entire monitoring program (the first and second phases together) was conducted over the four and a half-year period after initial/first cleanout.

Determining the need for cleanout was based on sediment depth measurements taken at regular intervals as part of the monitoring program. The maximum sediment depth allowed before cleanout had been set at two feet from the manufacturer's specifications.

In 2011, six (6) devices (RU01-04, RU04-02, RU06-01, RU07-01, RU14-01 and RU16-01) were found to have reached capacity and had to be cleaned out again. In 2012, four and one half years after the initial cleanout, additional four (4) devices at typical sites (RU01-02, RU01-03, RU02-01 and RU09-01) reached the cleanout trigger sediment depth. The last two (2) devices still had little bottom sediment accumulation due to improper installation or blockage of the inlet pipe, as observed during the previous project.

Table 2 shows the cleanout dates and sediment depths measured immediately before the second cleanout.

Table 2. Depth of Sediment Trapped and Removed (Six devices)

Site ID	First Cleanout Date	Second Cleanout Date	Sediment Depth in Grit Chamber at Second Cleanout
RU01-04	2008-01-11	2011-05-11	2.3 ft
RU04-02	2008-01-16	2011-05-19	2.0 ft
RU06-01	2008-02-28	2011-06-13	3.0 ft
RU07-01	2008-03-13	2011-06-14	3.9 ft
RU14-01	2008-05-08	2011-05-24	1.9 ft
RU16-01	2008-02-07	2011-06-03	2.2 ft

The measured sediment depths for all the twelve devices since the initial/first cleanout are shown in Figure 3. Not all the devices were cleaned out at the same time and the sediment depth measurements were not commenced simultaneously. By setting the cleanout time as time zero, the measured sediment depths are plotted again in Figure 4.

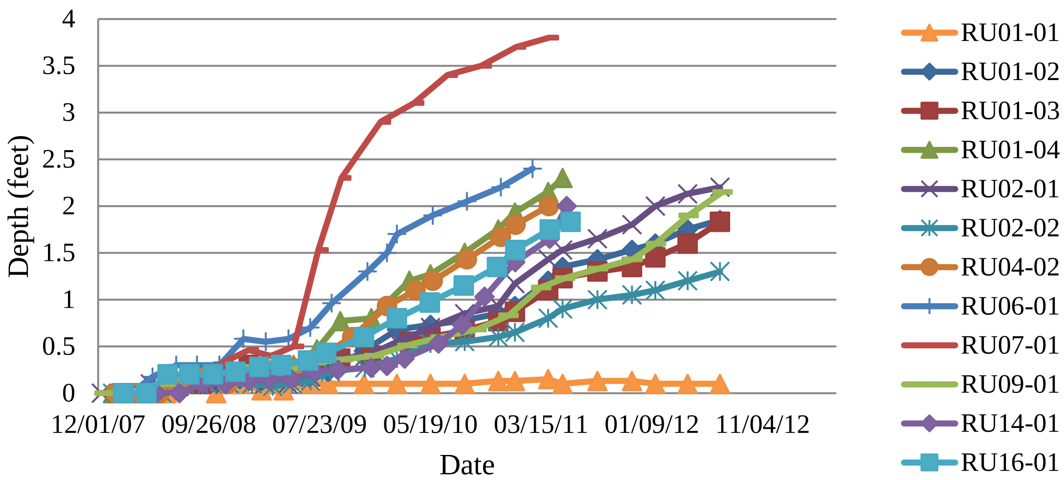

Figure 3. Measured depths of sediment accumulated at bottom of twelve devices during the monitoring program (December 1, 2007 to September 10, 2012)

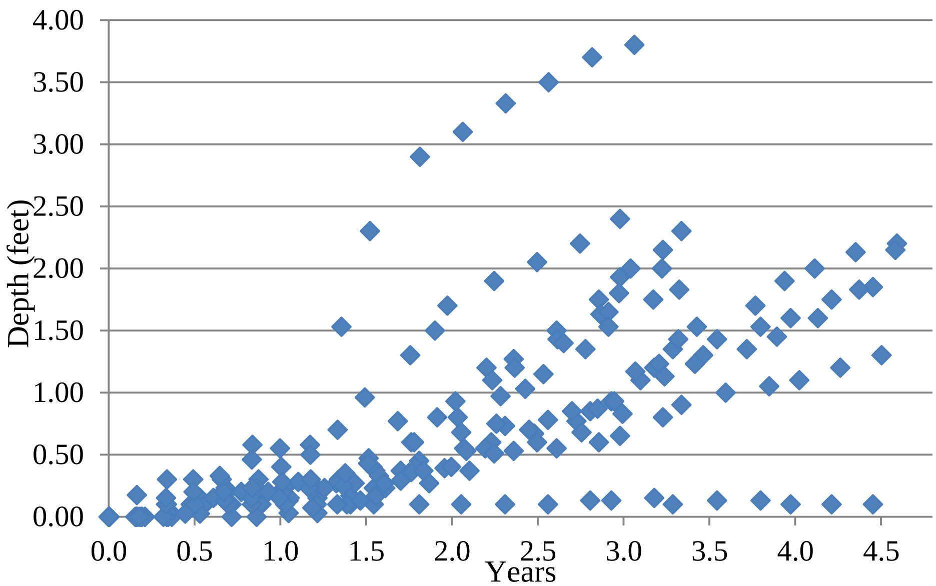

Figure 4. Depths of sediment accumulated on bottom of twelve devices during the monitoring program (December 1, 2007 to September 10, 2012). Time zero is the time of cleanout for each device.

During the entire monitoring program, depth of the sediment accumulation reached the cleanout trigger depth in 8 devices (RU01-04, RU02-01, RU04-02, RU06-01, RU07-01, RU09-01, RU14-01 and RU16-01). Two devices (RU01-02 and RU01-03) had their sediment depths almost reach the trigger depth (1.8 and 1.9 feet), but the other two devices (RU01-01 and RU02-02) only had low sediment depths, 0.1 and 1.3 feet, respectively, after four and one half years of monitoring.

MAINTENANCE INTERVAL

All MTDs require regular inspection and maintenance in order to ensure that the system performs as efficiently as possible. It is imperative to determine the optimum maintenance intervals. To achieve this goal, twelve (12) installed devices were selected for monitoring, analysis, and development of maintenance intervals.

The depth of sediment accumulation over the observation period (described in the previous section) was used as the lead indicator for the time interval between HDS cleanouts.

There are three types of sediment accumulation patterns so this study categorized the sites into three (3) conditions: typical site, heavy erosion, and improper installation. At typical sites with general conditions, the equation to determine the optimum maintenance intervals is developed based on the most effective variables identified.

Variables Affecting Sediment Accumulation

Additional research was deemed necessary on combined variables related to the increase in the amount of trapped materials on the device bottom. This research presents development and integration of information such as rainfall intensity and duration, highway drainage area characteristics, and traffic volume. Regression analysis has been performed to obtain a relationship between the cleanout interval and the variables.

<u>Information on Devices and Drainage Areas</u>

Data on the drainage area were obtained from the corresponding design companies or where not available, estimated from the NJDOT drainage plans. Information on devices was from the manufacturers' websites and/or brochures. Information on the connecting pipes, such as slope, length and diameter, was obtained from the NJDOT drainage plans. The collected information is shown in Table 3.

Table 3. Information on devices and drainage areas (Guo and Kim, 2013)

ID	Model	SS[a] (yd^3)	MPV[b] (gal.)	MTC[c] (cfs)	DA[d] (acres)	DA/CA[e] ($acre/ft^2$)	Pipe Slope	Design Traffic Data (vpd)
RU01-01	16000	7.1	2,774	25.2	4.97*	0.044	0.00357	37,000
RU01-02	7000	4.0	1,244	11.2	1.13*	0.023	0.00758	
RU01-03	7000	4.0	1,244	11.2	0.98*	0.020	0.01471	
RU01-04	7000	4.0	1,244	11.2	1.45*	0.029	0.01562	
RU02-01	16000	7.1	2,774	25.2	0.61*	0.005	0.00909	7,700
RU02-02	9000	4.8	1,582	14.2	0.61*	0.010	0.00556	
RU04-02	11000	5.6	1,947	17.5	7.70	0.097	0.00556	85,380
RU06-01	3000	1.8	506	4.4	1.18	0.059	0.00571	37,205
RU07-01	9000	4.8	1,582	14.2	1.28	0.020	0.04101	17,340
RU09-01	3000	1.8	506	4.4	0.49	0.025	0.01000	33,700
RU14-01	16000	7.1	2,774	25.2	2.45*	0.022	0.00152	36,420
RU16-01	5000	3.2	952	8.6	1.13*	0.030	0.00730	47,860

* Calculated approximate areas from drainage construction plans.

a. Sediment Storage (yd^3)

b. Maintenance "Pump Out" Volume (gallons)

c. Maximum Treatment Capacity (cfs)

d. Drainage Area (acres)

e. Drainage Area / Grit Chamber Area ($acres/ft^2$)

Precipitation

Average annual precipitation ranges from about 40 inches along the southeast coast to 51 inches in north-central parts of the State of New Jersey. Many areas have an average annual precipitation between 43 and 47 inches (ONJSC, 2009).

The data on daily precipitation at each site during the monitoring period was collected. Precipitation data were obtained from NJWxnet (New Jersey Weather and Climate Network) and NCDC (National Climatic Data Center). The annual precipitation from July

2007 to June 2008 at all the monitored sites is shown in Figure 5 that shows some spatial variation across the state.

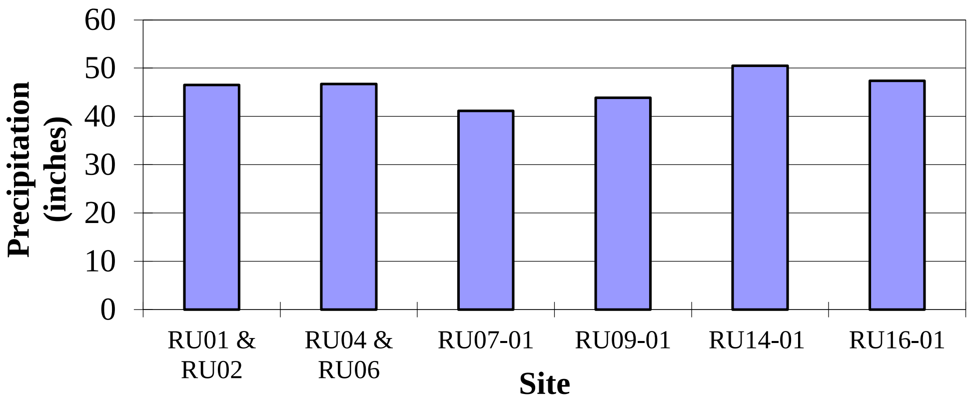

Figure 5. Precipitation in one year (07.01.2008 ~ 06.30.2009) at each site

Solids are carried by runoff from highways or major roads into the devices. Thus, the precipitation was initially considered as an important variable affecting the sediment accumulation. The accumulated precipitation is plotted against the accumulated sediment depth in Figure 6. It is hard to see a linear relationship between the precipitation and the sediment depth. Sometimes HDS collected more materials during the month with low rainfall but less materials during heavy rainfall. Therefore, the sediment accumulation may have more to do with the amount of sediment available to be washed into the device rather than the runoff volume available to wash.

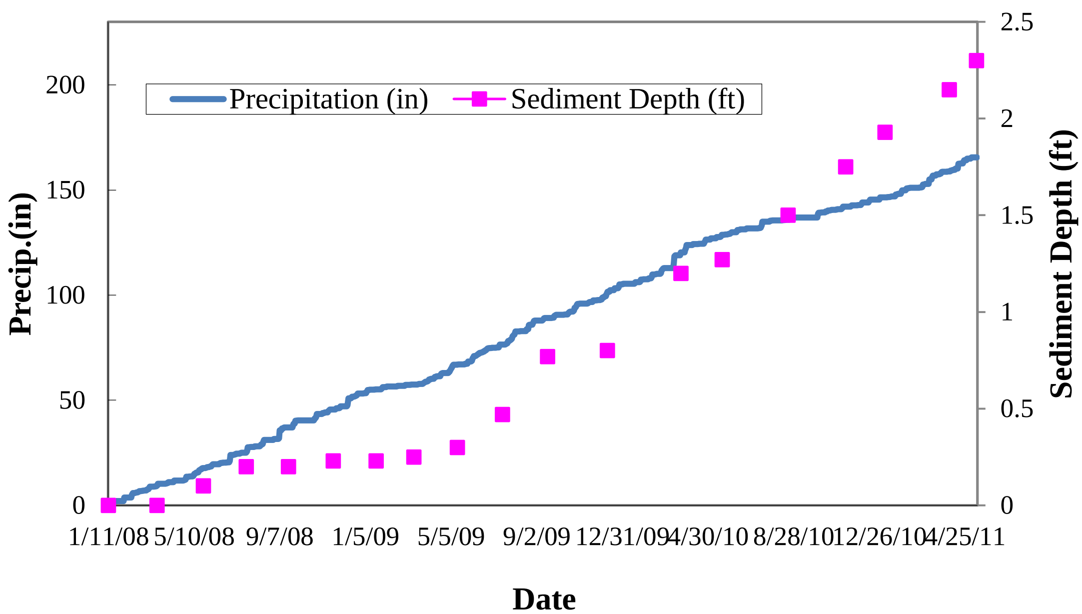

Figure 6. Precipitation and sediment accumulations for device RU 01-04

Recommended Cleanout Intervals

The depth of sediment accumulation over the observation period was used as the lead indicator for the time interval between HDS cleanouts. There is a wide variation of sediment accumulation among the devices due to the variables that affect it such as rainfall intensity and duration, drainage area size, traffic count, land use, source control, seasonality and deicing practices. Based on the most likely variables identified, this research divided the sites into three (3) categories of conditions to determine the optimum maintenance intervals.

Site Condition 1: Inadequate Flow in the Drainage Network

During the regular inspection, it was observed that various problems caused insufficient flow to the devices (Guo and Kim, 2010). These problems included an incorrectly constructed device, misaligned pipes, and blockage by debris or solids. In the case of RU01-01 for example, the depth of accumulated sediment varied between 0 and 0.1 feet over a period of three years after the initial cleanout (Figure 7). The large difference between the expected and observed results was found to be due to an incorrectly constructed diversion chamber. The stormwater runoff was not being diverted to the device, thus it was not receiving treatment. In the case of RU02-02, a blockage was detected in a pipe of the drainage network. That might have caused the low accumulated sediment depth (only 0.6 feet over three years) observed in the device (Figure 7). These problems need to be corrected.

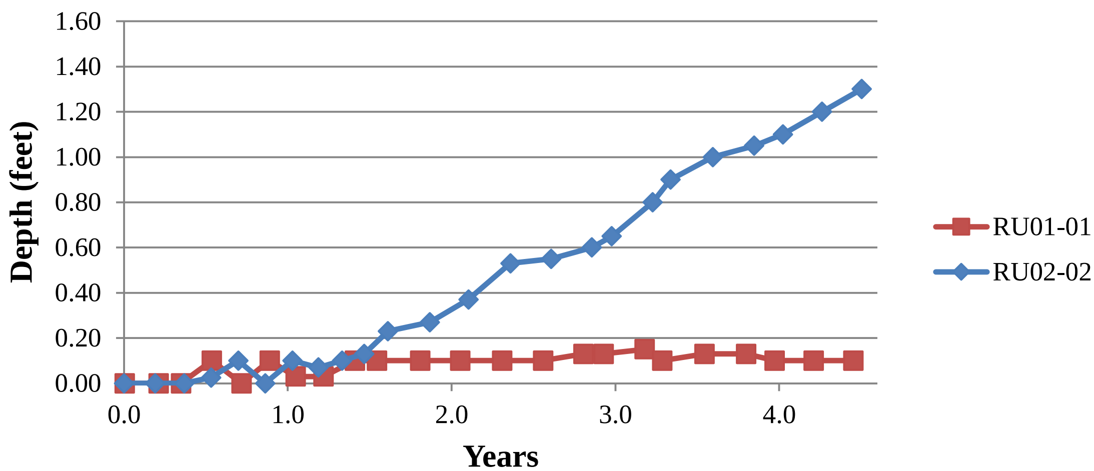

Figure 7. Sediment accumulation depth (Site Condition 1: inadequate flow in the drainage network)

Site Condition 2: Poor Source Control

Poor source control can cause severe erosion or deposition. Variation of sediment accumulation depth conforms to an S-shape curve when plotted (Figure 8). Due to the severe land surface erosion problems, devices require a maintenance interval of one and a half years (Guo and Kim, 2010).

At the site of RU06-01, construction activities (beneath the overpass) observed near Tonnelle Avenue contributed unusual amounts of sand to be washed into the storm sewers. Additionally, there was a significant amount of mush sediment on the roadway directly in front of the bridge scupper. This mush sediment was washing directly into the catch basin nearest the device and was settled in the swirl/grit chamber.

At the site of RU07-01, it was noticed that driveways from a farm comprised mostly of sand were eroding and the sand was being washed into the network. Large amounts of deposited sand were also observed on the driveways of a nearby construction area. The combination of eroded sand from the farm, deposited sand from construction activity, heavy rain events (51.16 inches between September 25th 2008 and September 24th 2009), and steep roads were responsible for an unusual increase in the amount of accumulated sediment.

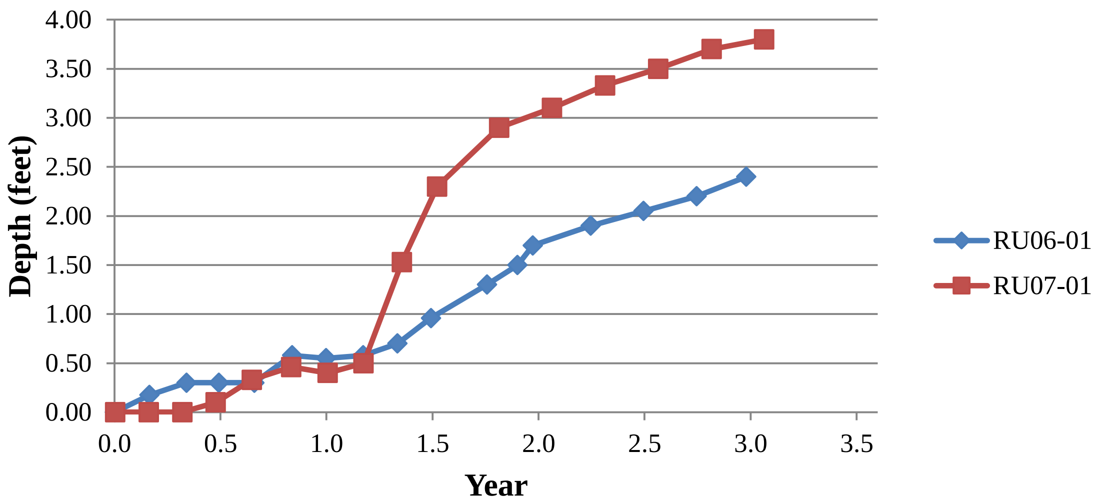

Figure 8. Sediment accumulation depth (Site Condition 2: Poor source control)

Site Condition 3: Sites Under General Conditions

By the time of May to June, 2011, four devices (RU01-04, RU04-02, RU14-01 and RU16-01) had reached or almost reached the cleanout trigger sediment depth (2 feet), they were cleaned out. These four devices are generally located in more urban and high traffic areas. The sediment depths in four other devices (RU01-02, RU01-03, RU02-01 and RU09-01) had not reached the trigger sediment depth and were continued to be monitored. They are located generally in rural and low traffic areas. The time variation of bottom sediment depths for all the eight devices under the general site conditions are plotted in Figure 9.

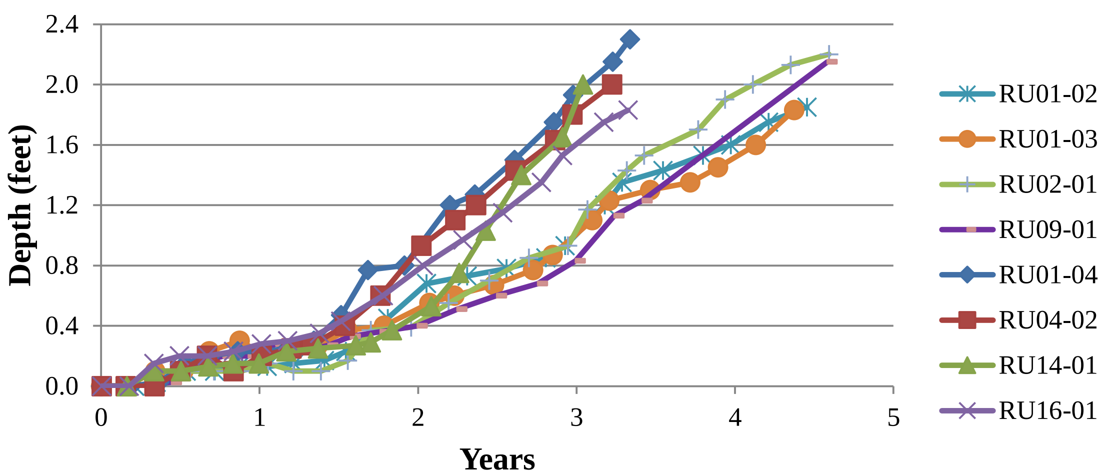

Figure 9. Sediment accumulated depth (Site Condition 3: General conditions)

It is expected that both the traffic volume (a direct source of the solids deposit) and the impervious surface area (a collector of the atmospheric solids deposition) would have primary influences on the amount of sediment available to be washed into the device and consequently, the device bottom sediment accumulation and the cleanout interval. From Figure 9, it appears there are two clusters of sediment accumulation curves and cleanout intervals. The devices in the higher cluster are generally located in the urban and high traffic area and appear needed to be cleaned out every three years. The devices in the lower cluster are generally located in the non-urban low traffic area and appear needed to be cleaned out every four and one half years.

An effort was made in this research to combine the influences of both traffic volume and the impervious area and to predict the cleanout interval based on these two primary influencing factors.

The cleanout interval should be inversely and nonlinearly related to the rate of the sediment load into the device. And, the rate of the sediment load could be assumed to be linearly related to the traffic volume and the impervious drainage area.

The sediment/solids load to the device per hour (S_t) is assumed to be linearly related to the rate of solids deposition from vehicle (w_1) and the rate of solids load from impervious drainage area (w_2) as follows:

$$S_t = w_1 N_v + w_2 Ai \quad (1)$$

where,

S_t = Sediment/solids load to the device per hour (g/hr)
w_1 = Solids load from a vehicle per hour (g/vehicle/hr)
w_2 = Solid load from drainage area per hour (g/acre/hr)
N_v = Number of vehicles on the road(s) related with the device
Ai = Impervious drainage area for the device (acre)

The number of the vehicles on the road(s) across the drainage area of the device (N_v) can be related to the length of the road(s) (miles), the vehicle speed limit (miles per hour), and the traffic count (the number of vehicles per hour) and calculated as follows:

$$\mathrm{Nv} = \frac{\text{Length of road (miles)}}{\text{Speed Limit}\left(\frac{\text{miles}}{\text{hr}}\right)} \times \mathrm{vph}\left(\frac{\text{vehicles}}{\text{hr}}\right) \quad (2)$$

Table 4 below shows data on the actual traffic count, the speed limit, the length of road(s), the impervious drainage area, the cleanout interval, and the total sediment mass accumulated at the time of cleanout for each of the eight devices at normal sites.

Note that the difference between the traffic counts listed in Tables 3 and 4. The former is the traffic count for designing the major road(s) for the monitoring site, while the latter is the traffic count actually conducted for the road(s) related to the particular device. The mass of sediment in Table 4 (the last column on the right) was calculated by multiplying the calculated volume of the bottom sediment at the cleanout (the bottom surface area times the two-feet trigger depth) by the average sediment bulk density (1.26 g/cm^3) based on the actual measurements. The sediment loading rate (S_t) is calculated from dividing the mass of sediment trapped in the device by the cleanout interval.

Among the eight devices, drainage areas (Table 4) for the two devices RU04-02 and RU9-01 were directly obtained from the design reports rather than estimated from the maps and thus they are most accurate. Coincidently, the drainages areas for these two devices (7.7 and 0.49 acres, respectively) also happened to be the largest and the smallest among the eight, and they are the two most impervious (92% and 97% impervious, respectively) as well. The data from these two devices were used to solve simultaneously for w_1 and w_2. The solved values of w_1 and w_2 are 2.2 (g/vehicle/hr) and 53 (g/acre/hr), respectively. The values of w_1 and w_2, in more commonly used units, are 42 pounds per vehicle per year and 1,000 pounds per acre per year, respectively.

Table 4. Information on Traffic Count, Drainage Area, Cleanout Interval, and Sediment Accumulation

Site ID	Traffic Count (number per hour)	Road Length (miles)	Speed Limit (miles per hour)	Impervious Drainage Area (acres)	Cleanout Interval (yrs)	Device Diameter (ft)	Mass of Sediment Trapped in Device (kg)
RU01-02	925	0.16	35	0.61	4.48	8	3,580
RU01-03	861	0.16	25	0.60	4.55	8	3,580
RU01-04	2,360	0.10	25-45	1.66	3.06	8	3,580
RU02-01	1,249	0.07	35-45	1.02	4.16	12	8,090
RU04-02	2,243	0.16	25-40	3.54	3.15	10	5,650
RU09-01	1,940	0.11	40	0.48	4.49	5	1,430
RU14-01	4,710	0.25	35-50	2.18	3.04	12	8,090
RU16-01	1,672	0.13	35-55	1.47	3.46	7	2,720

With the values of w_1 and w_2, the sediment/solids load to the device per hour (S_t) can be estimated using the given number of vehicles on the road related with the device and the impervious drainage area for the device (acre). The number of the vehicles on the road can be calculated from the traffic count, the road length, and the speed limit as indicated above or from counting all the vehicles on the road(s) from an aerial photograph.

Assuming a nonlinear logarithmic relationship between the cleanout interval and the sediment load, the data from all the eight devices (Table 4) were used to determine the coefficients that would offer the best fit. The fitted relationship is as follows:

$$y = - 0.99 \ln (S_t) + 8.1 \qquad (3)$$

where,

y = Device cleanout interval (yr)

S_t = Sediment/solids load to the device per hour (g/hr)

The fitted curve along with the data from all the eight devices are shown in Figure 10. It is a very good fit with the R^2 (the coefficient of determination) value of 0.87.

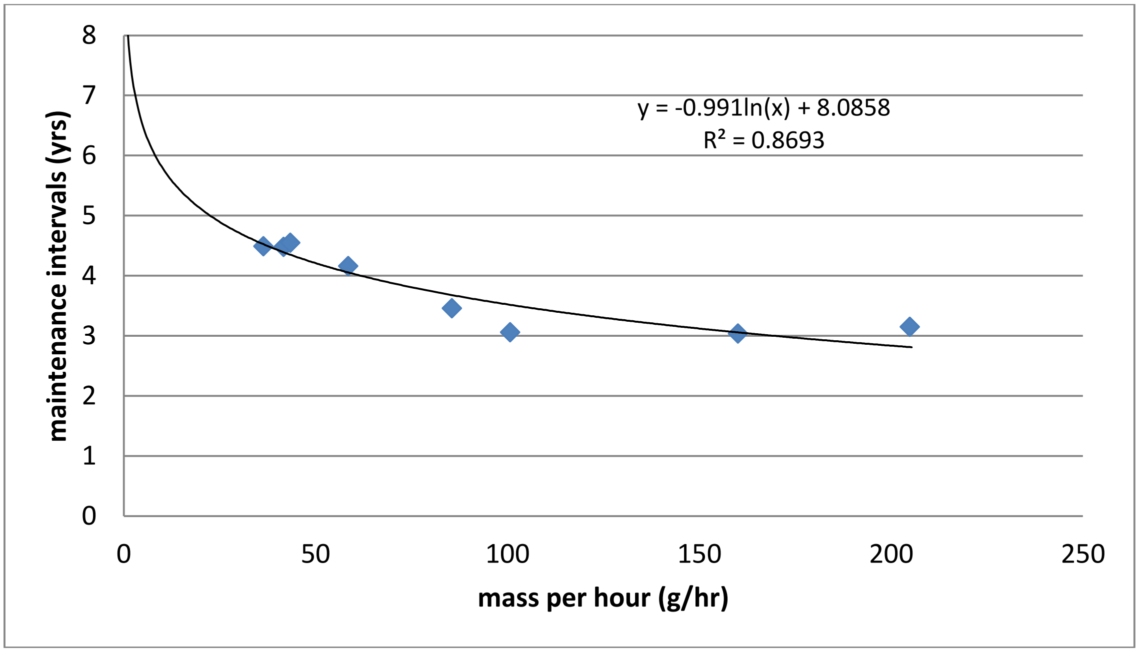

Figure 10. Relation between maintenance interval and sediment load to device

The above fitted model based on the traffic volume and the impervious area can be used to predict the cleanout/maintenance interval. This will be more accurate than the four-year interval roughly extrapolated during the previous research project.

All the devices monitored were sized based on NJDEP's previous water quality design storm (WQDS) with 1.25 inches of rainfall depth uniformly distributed over two hours. The updated design storm still has 1.25 inches of rainfall depth but non-uniformly distributed (NJDEP, 2004). This updated WQDS may lead to the use of a larger device for the same drainage area. The maintenance interval for the device sized based on the updated WQDS may be longer than the one predicted using the relationship established in this study, and it can be increased proportionally to the increase in the bottom surface area.

For other types of hydrodynamic separators, the maintenance interval can be adjusted based on the proportion of the maximum allowable sediment storage volume.

CONCLUSIONS & RECOMMENDATIONS

Twelve (12) hydrodynamic separators (HDSs), a type of stormwater manufactured treatment device (MTD), were continuously monitored after the end of the previous research project to gain confidence in the previously projected device maintenance intervals.

The sites for the twelve devices were divided into three different categories: (1) sites with inadequate inflow to the device, (2) sites with the poor source control, and (3) sites under general conditions. For the sites with inadequate inflow, the installation problems should be corrected and/or the inlet pipes should be cleared. For the sites with poor source control, a maintenance interval of one and one half years is recommended, but, it is preferably recommended that they are made stable, to reduce the degree of erosion, and then put on a maintenance interval for the general sites. For the general sites, the maintenance intervals were measured to be from three to four and one half years. For planning future maintenance/cleanout activities, it is recommended that the predictive model be used with the number of vehicles on the road(s) and the impervious drainage area as inputs.

For the same type of devices or other types of devices, the maintenance interval can be predicted first using the same relationship obtained from this study and then adjusted proportionally based on the ratio of the maximum allowable bottom sediment storage volumes.

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