# SAFL Baffle Research Summary

Four years of research was conducted to develop and test the SAFL Baffle. The research took place at the University of Minnesota's St. Anthony Falls Laboratory and was funded by the Minnesota Department of Transportation. Links to SAFL Baffle project reports and publications can be found at the end of this document. In this research summary, the following four topics will be discussed:

1. SAFL Baffle Performance
2. Effects of Trash and Vegetation
3. 90 Degree Outlet Sump Manholes
4. Sump Manholes with Inlet Grates and Inlet Pipes

## SAFL Baffle Performance

SAFL Baffles are installed in existing or new construction sump manholes. Without a SAFL Baffle, sump manholes capture sediment found in stormwater during rain storms through settling. During intense storm events, however, this previously captured sediment can be washed out of the sump due to a circular water flow pattern. With the SAFL Baffle installed in a sump manhole, water is unable to travel in a circular pattern. During most low intensity storm events, slightly more sediment is captured in the sump than without the SAFL Baffle. But during intense storm events, the SAFL Baffle prevents the circular water flow pattern to form inside of the sump manhole. This prevents washout of sediment (Howard et al. 2010).

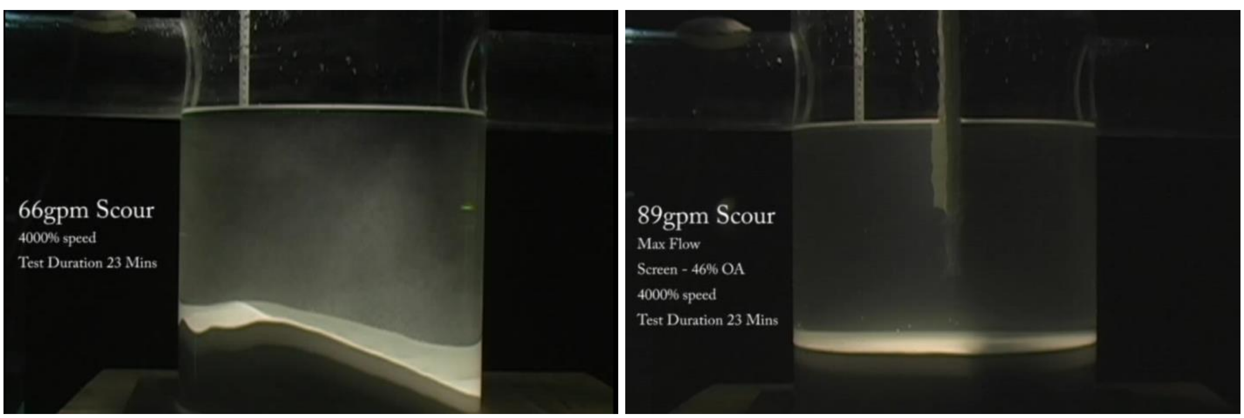


**Figure 1: Sediment deposits in a scale model sump manhole after a high flow rate test. (Left) Without a SAFL Baffle & (Right) With a SAFL Baffle (Howard et al. 2011).**

Several stormwater treatment devices were tested at St. Anthony Falls Laboratory in addition to the SAFL Baffle. The performance of all these devices was characterized using by measuring (1) how well the device captures sediment and (2) how well it retains sediment at high flow rates. The first metric is called Removal Efficiency, and can be characterized in terms of the Péclet number over the Froude number of the inlet jet velocity versus the amount of sediment captured in terms of a fraction. And the second metric is called Washout Performance, and can be characterized in terms of Péclet number over the Froude number of the inlet jet velocity versus a dimensionless concentration number called $\hat{C}$. The Péclet number, the Froude number of the inlet jet velocity and the dimensionless concentration number are shown below. By using these dimensionless numbers, it is possible to compare the Removal Efficiency and Washout Performance of different devices, different sized devices, different sediment particle sizes, and different flow rates (McIntire, et al. 2012).

$$Péclet\ Number = Pe = \frac{v_s * h * D}{Q}$$

*Where:*

$v_s = settling\ velocity\ of\ sediment\ particles$
$h = sump\ depth$
$D = sump\ diameter$
$Q = flow\ rate\ entering\ sump$

$$Froude\ Number = {Fr_j}^2 = \frac{U^2}{gD}$$

*Where:*

$U = velocity\ of\ waterjet\ entering\ the\ sump$
$g = acceleration\ of\ gravity$
$D = sump\ diameter$

$$Dimensionless\ Concentration\ Number = \hat{C} = \frac{C(SG-1)}{\rho_w SG}$$

*Where:*

$C = effluent\ concentration$
$g = acceleration\ of\ gravity$
$\rho_w = water\ density$
$SG = specific\ gravity\ of\ particles$

The Removal Efficiency of a sump manhole with and without a SAFL Baffle is shown below in Figure 2. Tests were conducted by starting with an empty sump manhole, feeding set sediment sizes into the sump at various flow rates with and without a SAFL Baffle, and measuring the amount of sediment captured. On the figure, low $Pe/{Fr_j}^2$ values correspond to small sump manholes, experiencing high flow rates, and receiving small sediment particles, and high $Pe/{Fr_j}^2$ values correspond to large sump manholes, experiencing low flow rates, and receiving large sediment particles. This means that a curve laying left of another curve captures more sediment. Figure 2 shows that a SAFL Baffle installed in a sump manhole will capture 10-15% more sediment than a sump manhole without a SAFL Baffle (McIntire, et al. 2012).

The Washout Performance of a sump manhole with and without a SAFL Baffle is shown below in Figure 3. Tests were conducted by starting with a sump manhole partially filled with sediment, increasing the flow rate to match a storm flow rate, and measuring how much sediment was washed out of the sump. On the figure, $Pe/{Fr_j}^2$ values correspond to the same conditions as described for Figure 2. High $\hat{C}$ values correspond to high sediment effluent concentrations (the concentration of sediment leaving the sump). Figure 3 shows that without a SAFL Baffle, previously captured sediment will wash out of the sump manhole. With the SAFL Baffle, however, washout is significantly decreased to near negligible levels, depending on flow rate (Howard et al. 2011).

The washout benefits of using a SAFL Baffle can be plainly seen in Figure 4. When a SAFL Baffle is not installed in a sump manhole, washout increases exponentially with an increase in flow rate. Effluent concentrations were measured as high as 800 mg/L at a flow rate of 16 cubic feet per second (cfs). With a SAFL Baffle, washout dramatically decreases. At the same flow rate of 16 cfs, the effluent concentration was measured was less than 50 mg/L. And with the SAFL Baffle, below 7 cfs, the effluent concentration measured was negligible (McIntire, et al. 2012).

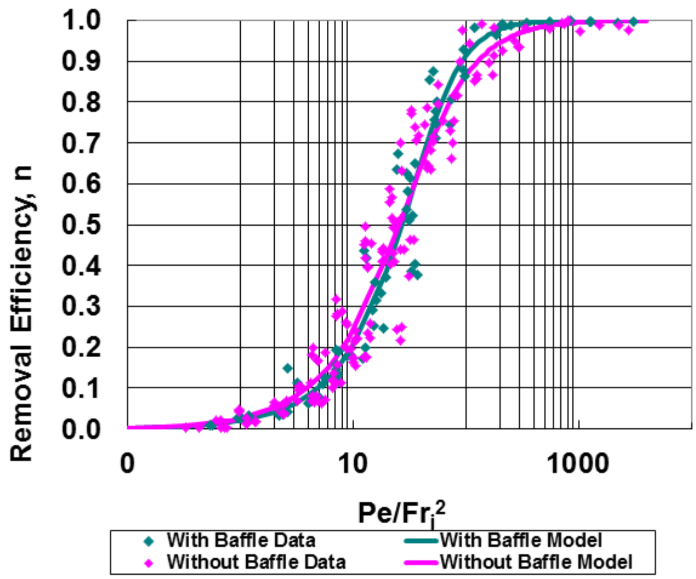


**Figure 2: Removal Efficiency of a sump manhole with and without a SAFL Baffle (From Howard et al. 2011)**

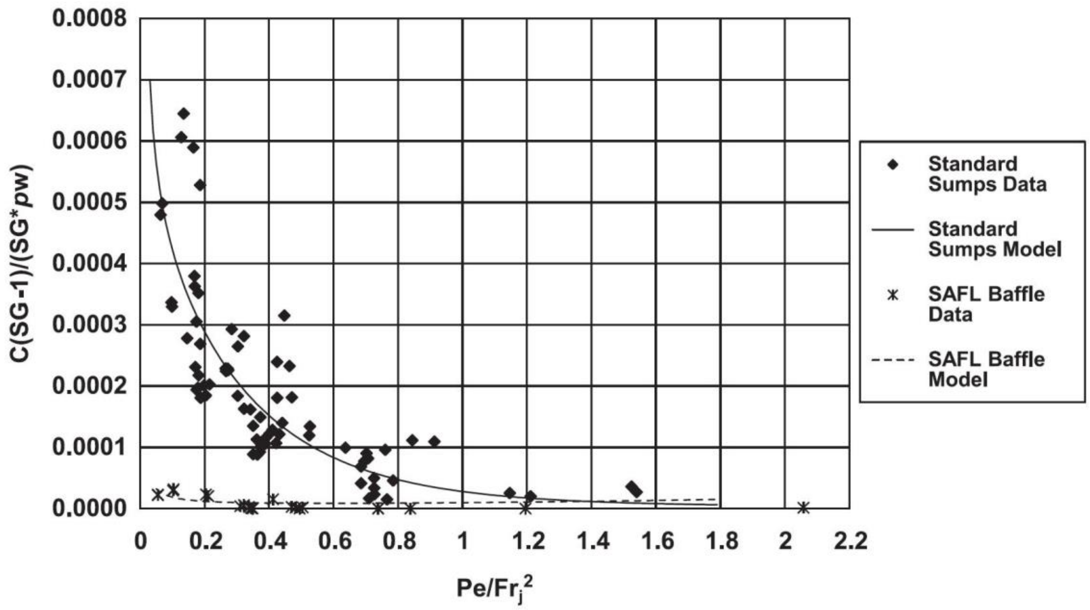


**Figure 3: Washout Performance of a sump manhole with and without a SAFL Baffle (From Howard et al. 2011)**

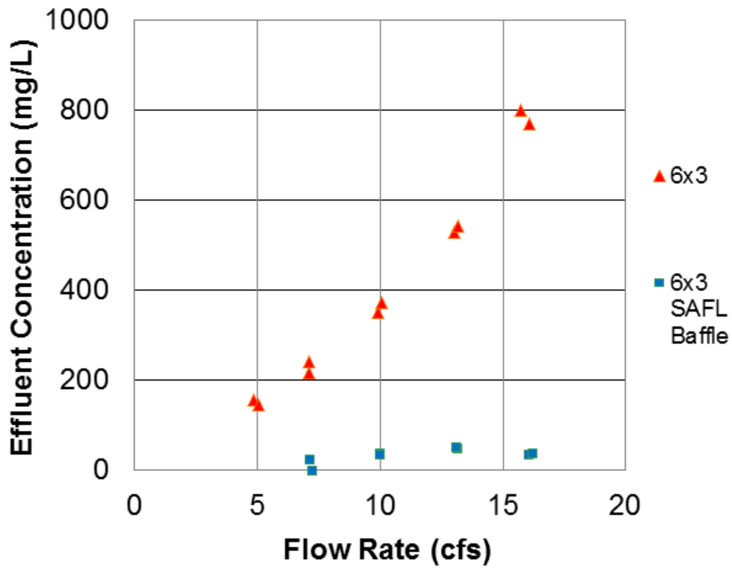


**Figure 4: Washout Performance of a 6-ft diameter, 3-ft deep sump manhole with and without a SAFL Baffle (From Howard et al. 2011)**

## Effects of Trash and Vegetation

Stormwater debris like trash and vegetation can affect all stormwater treatment devices. To understand the effects of trash and vegetation on sump manholes equipped with the SAFL Baffle, a year of research was conducted at St. Anthony Falls Laboratory. The research determined what makes up debris in stormwater, and how will it affect the SAFL Baffle. Tests were completed by inundating a sump manhole with debris, and measuring the effects on Removal Efficiency and Washout Performance (McIntire, et al. 2012).

Researchers concluded that sump manholes that are nearly as deep as they are in diameter will experience no change in Washout Performance due to debris clogging. Sump manholes that are about half as deep as they are in diameter will experience a decrease in Washout Performance due to debris clogging. Figure 5 illustrates this point by showing two scale model sump manholes equipped with a SAFL Baffle, inundated with debris, and the resulting washout of sediment. Both of the sump manholes have depths equal to about half of their diameter, but the image on the left has a SAFL Baffle with hole sizes equal to three inches, and the image on the right has a SAFL Baffle with hole sizes equal to five inches. This indicates that the decrease of Washout Performance due to clogging on shallow sump manholes can be mitigated by using a SAFL Baffle with larger hole sizes (McIntire et al. 2012).

Figures 6 and 7 show the effects of trash and vegetation on the Removal Efficiency and Washout Performance of sump manholes equipped with SAFL Baffles. Figure 6 indicates that debris has little to no effect on Removal Efficiency. Figure 7, however, shows that at high flow rates, clogging can create washout of sediment. The results shown in Figure 7 indicate that deep sumps do not experience much washout, even when clogged with debris. Shallow sumps, on the other hand, experience washout due to clogging. By using a 5 inch hole diameter SAFL Baffle, this washout problem can be mitigated. The results found during full scale testing match with the results found during scale model testing (McIntire, et al. 2012).

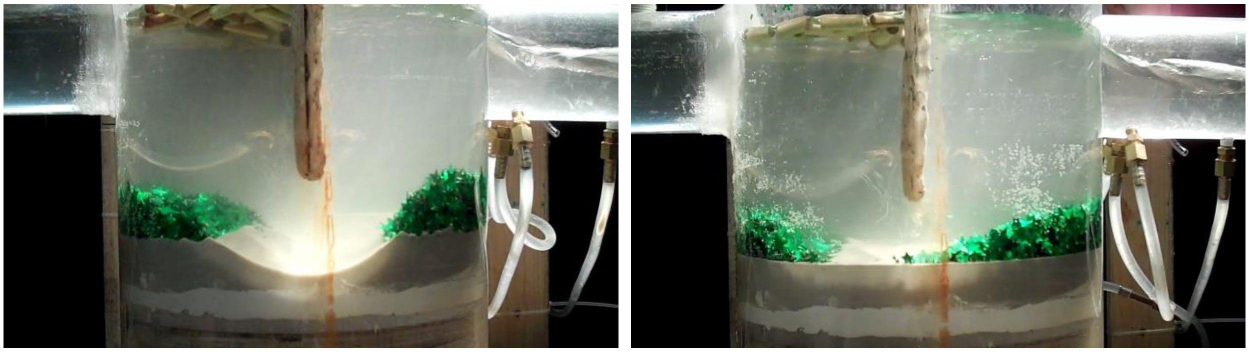

**Figure 5: Washout of sediment measured due to debris clogging the SAFL Baffle. (Left) A 3 inch hole diameter SAFL Baffle installed in a sump manhole and (Right) a 5 inch hole diameter SAFL Baffle installed in a sump manhole (From McIntire et al. 2012).**

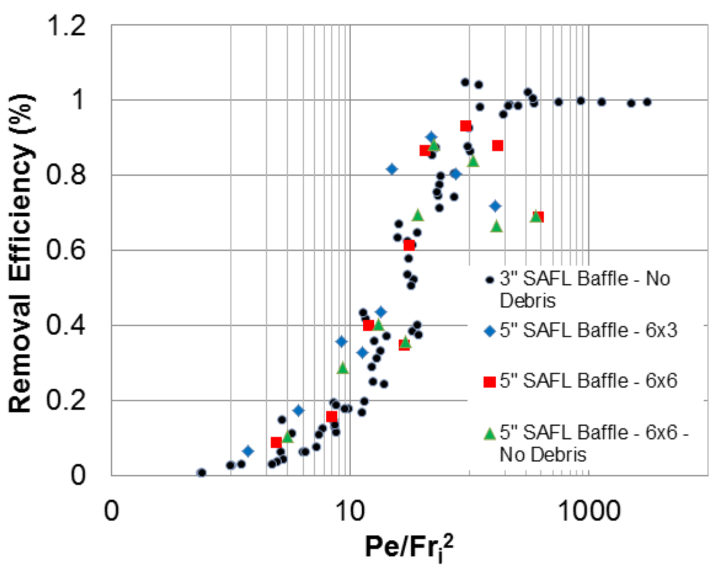


**Figure 6: The effects of debris on Removal Efficiency. Debris has little to no effect on the Removal Efficiency of sump equipped with a SAFL Baffle (From McIntire, et al. 2012).**

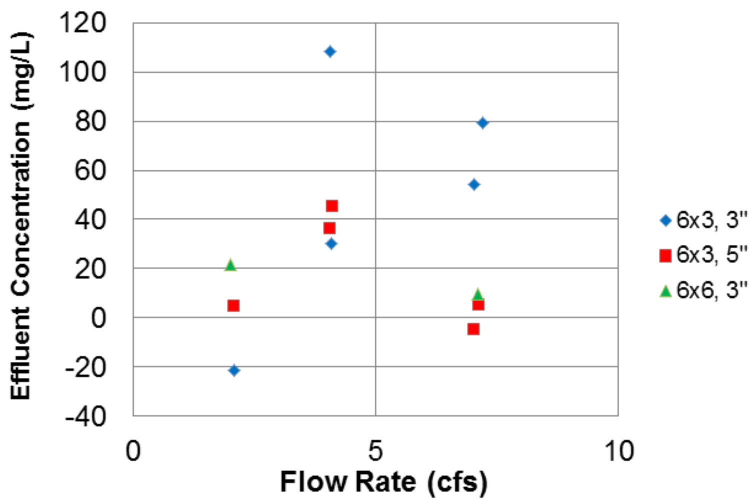


**Figure 7: Washout of sediment measured due to debris clogging the SAFL Baffle. Deep sump manholes (ex. 6-ft diameter and 6-ft deep (6x6)) with a SAFL Baffle experience negligible washout, and shallow sump manholes (ex. 6-ft diameter and 3-ft deep (6x3) with a SAFL Baffle experience washout. Using a 5 inch hole diameter SAFL Baffle mitigates the washout problem for shallow sump manholes (From McIntire et al. 2012).**

## 90 Degree Outlet Sump Manholes

Not all sump manholes have an outlet pipe that is located 180 degrees to the inlet pipe. Some have outlet pipes that are located 90 degrees to the inlet pipe (See Figure 8). Scale model tests were conducted at St. Anthony Falls Laboratory to determine the optimum orientation of a SAFL Baffle in a 90 degree outlet sump manhole. Next, Removal Efficiency and Washout Performance tests were conducted on a full scale, 6-ft diameter by 6-ft deep sump manhole equipped with a SAFL Baffle oriented 113 degrees to the inlet pipe.

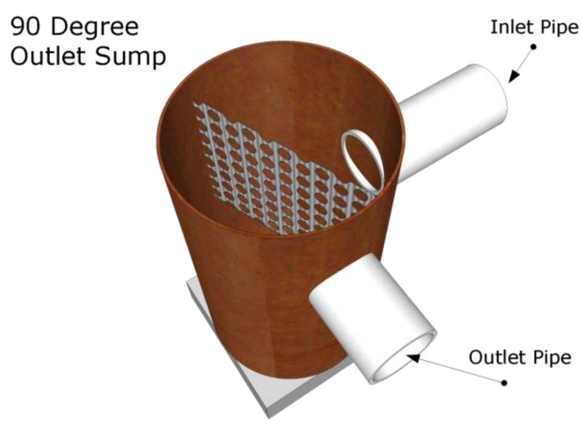


**Figure 8: A SAFL Baffle installed in a 90 degree outlet sump manhole at a 113 degree angle with respect to the inlet pipe (From McIntire et al. 2012).**

Scale model tests indicate that sump manholes with 90 degree outlet pipes will experience significant washout during high flow rates. However, when a SAFL Baffle is installed at a 90 degree angle relative to the inlet pipe, washout is negligible. Tests were completed at angles in between 90 and 180 degrees with respect to the inlet pipe, under otherwise similar conditions. Figure 10 shows these scale model results. The results indicate that washout of sediment is negligible when the SAFL Baffle is installed between 90 and 120 degrees.

**Figure 9: The sediment bed after conducting a high flow rate Washout Performance test on a 90 degree outlet sump. (Left) Without a SAFL Baffle and (Right) with a SAFL Baffle installed at 90 degrees with respect to the inlet pipe (From McIntire et al. 2012).**

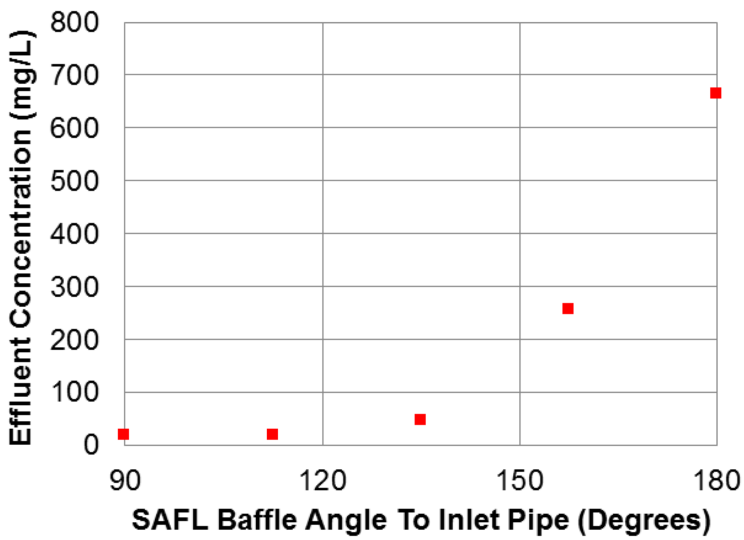


**Figure 10: Washout of sediment at high flow rates for a 90 degree outlet sump with a SAFL Baffle installed at angles between 90 to 180 degrees with respect to the inlet pipe (From McIntire, et al. 2012).**

Tests on a 6-ft diameter, 6-ft deep sump manhole were conducted with a SAFL Baffle installed at a 113 degree angle with respect to the inlet pipe. This is within the range of negligible washout as indicated by the scale model testing. Figure 11 shows Removal Efficiency results, and indicates increased Removal Efficiency when compared to a straight flow through sump manhole with a SAFL Baffle installed at a 90 degree angle with respect to the inlet pipe (also called Standard Sumps). Figure 12 shows the Washout Performance results, and indicates that washout increases with flow rate. At a flow rate of 12 cfs, washout is at a maximum of about 62 mg/L (McIntire et al. 2012).

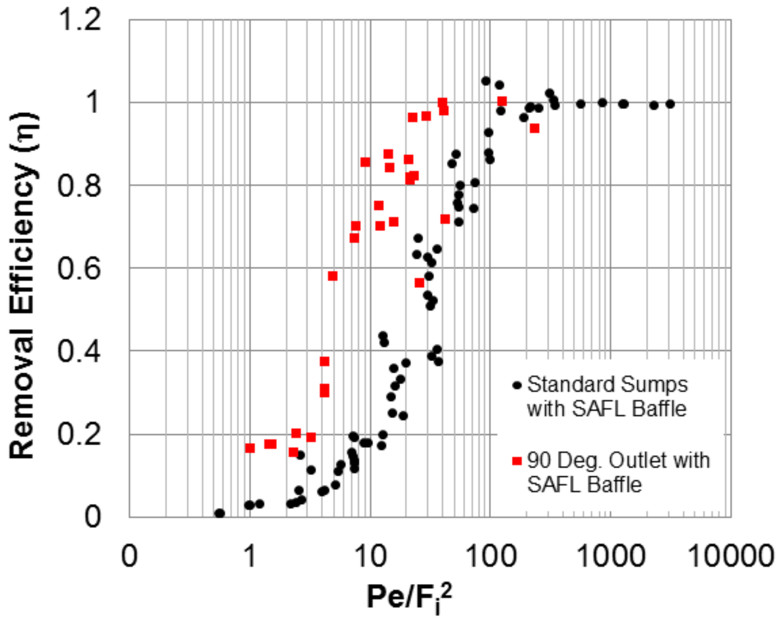


**Figure 11: Removal Efficiency results of a 6-ft diameter, 6-ft deep sump manhole with a 90 degree outlet and a SAFL Baffle installed at a 113 degree angle with respect to the inlet pipe (McIntire et al. 2012).**

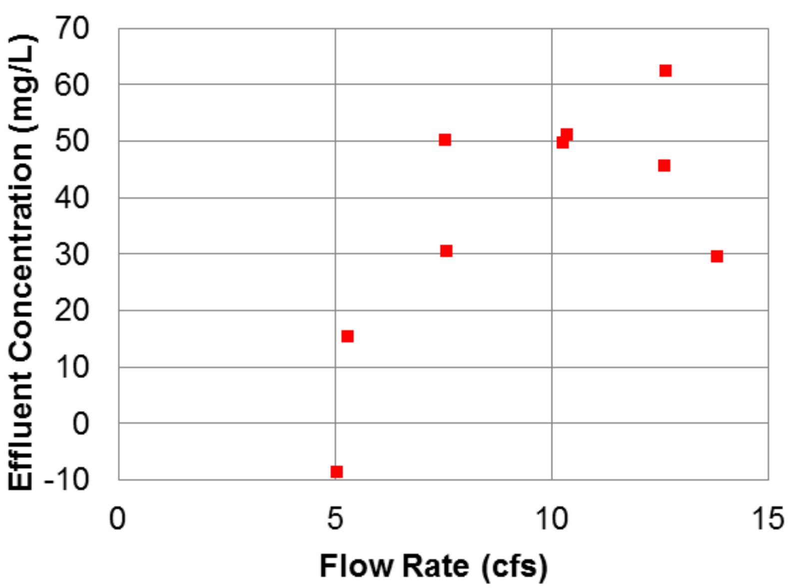


**Figure 11: Washout Performance results of a 6-ft diameter, 6-ft deep sump manhole with a 90 degree outlet and a SAFL Baffle installed at a 113 degree angle with respect to the inlet pipe (McIntire et al. 2012).**

# Sump Manholes with Inlet Pipes and Inlet Grates

Some sump manholes receive water from both an inlet pipe and an inlet grate from above. To know how the inlet grate water will affect the Removal Efficiency and Washout Performance of the system, tests were completed at St. Anthony Falls Laboratory. A test stand (see Figure 12) was built and included a 6-ft diameter, 6-ft deep sump manhole equipped with a SAFL Baffle and a simulated road surface with an inlet grate. Water could be sent through this system through the inlet pipe and the simulated road surface simultaneously. The SAFL Baffle was installed traditionally, at a 90 degree angle with a respect to the inlet pipe. The inlet grate was located such that half of it was upstream of the SAFL Baffle and half was downstream. Removal Efficiency tests were completed by maintaining a constant inlet grate flow rate of 0.4 cfs through all of the tests, and varying the flow through the inlet pipe. Washout Performance tests were completed by maintaining a constant inlet grate flow rate of 0.7 cfs through all of the tests, and varying the flow rate through the inlet pipe.

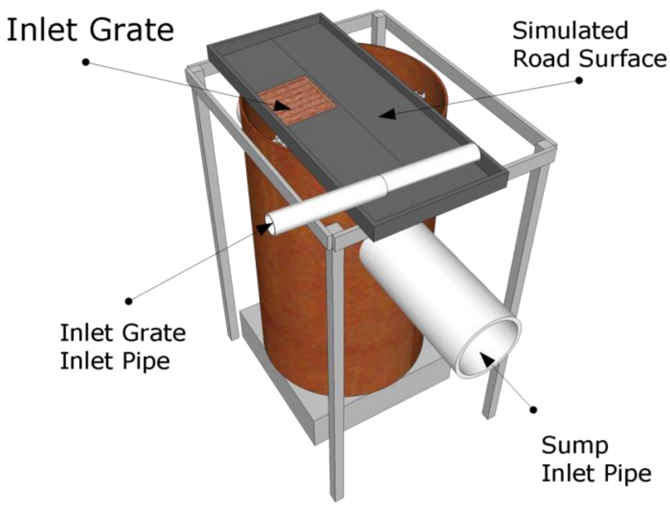


**Figure 12: A 3D rendering of the test setup used for testing a SAFL Baffle installed in a sump that receives water from both an inlet pipe and an inlet grate (From McIntire et al. 2012).**

Figure 13 shows the Removal Efficiency data for the inlet grate sump manhole testing. The results indicate that this type of system will capture sediment as well as a Standard Sump manhole equipped with a SAFL Baffle. However, if the flow through the inlet pipe was less than three times that through the inlet grate, Removal Efficiency was decreased and was less than a Standard Sump manhole equipped with a SAFL Baffle. The researchers theorized that water entering the sump through the inlet grate was able to plunge deeper into the water below if flow rates through the inlet pipe were low. The plunging reduced the ability of the sump & SAFL Baffle to capture sediment (McIntire, et al. 2012).

Figure 14 shows the Washout Performance data for the inlet grate sump manhole testing. The results indicate that, if the inlet grate flow rate is held constant, washout decreases as the flow rate through the inlet pipe increases. This matches with results found during the Removal Efficiency tests described above. Water from the inlet grate plunges deeper into the sump when flows through the inlet pipe are low, resulting in washout of sediment. Washout is negligible as long as the flow through the inlet pipe is three times that of the flow through the inlet grate (McIntire, et al. 2012).

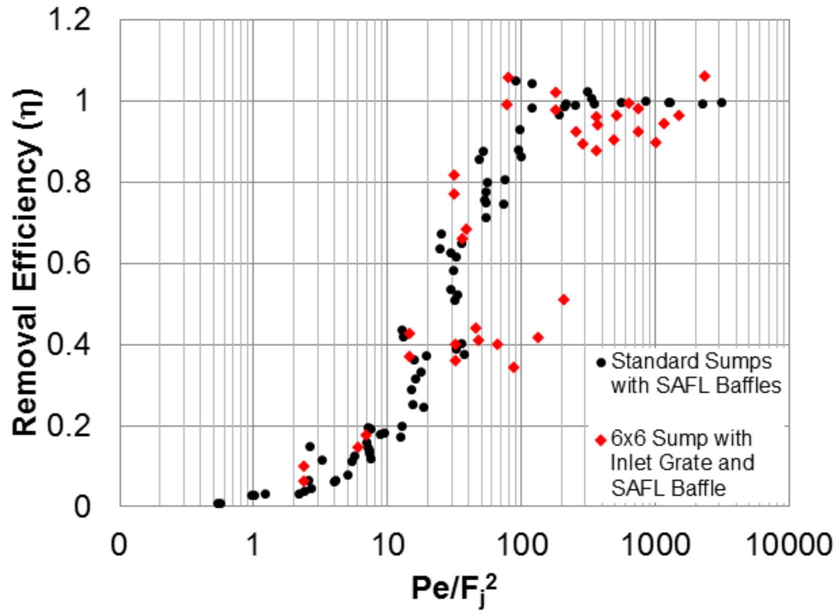


**Figure 13: Removal Efficiency data from the inlet grate sump manhole (McIntire, et al. 2012).**

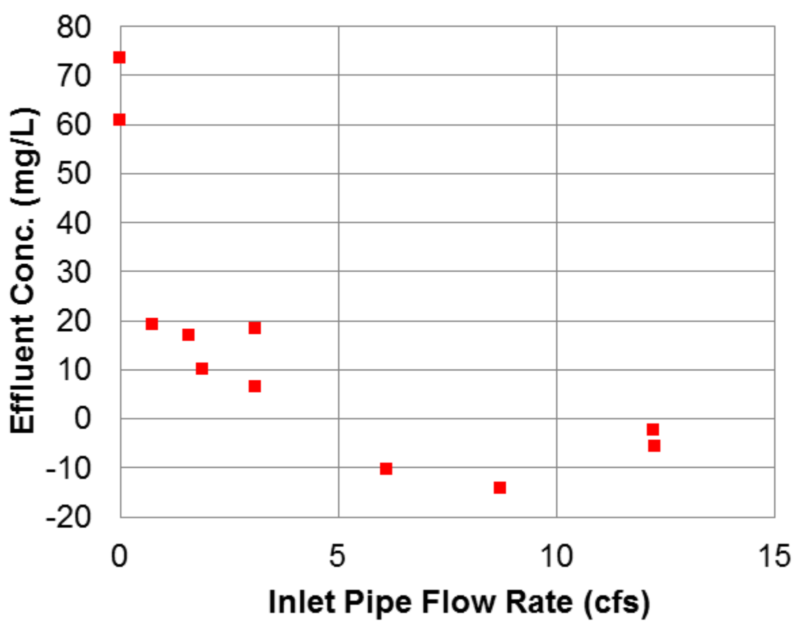


**Figure 14: Washout Performance data for the inlet grate sump manhole (McIntire, et al. 2012).**

## References

Howard, A., O. Mohseni, J.S. Gulliver, and H.G. Stefan. *Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practice for Stormwater Treatment (Volume 1)* (St. Paul: Mn/DOT Research Services Report, Feb. 2011).

Howard, A., O. Mohseni, J.S. Gulliver, and H.G. Stefan. "SAFL Baffle Retrofit for Suspended Sediment Removal In Storm Sewer Sumps," *Water Research* 45 (2011): 5895-5904.

McIntire, K., A. Howard, O. Mohseni, and J.S. Gulliver. Assessment and Recommendations for the Operation of Standard Sumps as Best Management Practice for Stormwater Treatment (Volume 2) (St. Paul: Mn/DOT Research Services Report, Feb. 2011).

## Further Resources

http://www.dot.state.mn.us/research/TS/2011/201108.pdf
http://stormwater.safl.umn.edu/content/updates-december-2011
http://stormwater.safl.umn.edu/content/updates-december-2010