Evaluating Scour Potential in Stormwater Catchbasin Sumps Using a Full-Scale Physical Model and CFD Modeling

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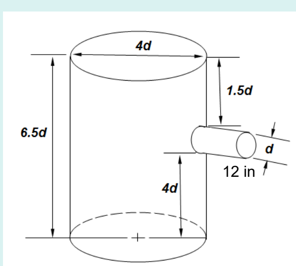
Introduction

- Sediment removal measurements in catchbasin sumps and hydrodynamic separators does not necessarily imply the prevention of scour of previously captured sediment.
- Understanding scour mechanisms and losses in catchbasins and similar devices is critical when implementing stormwater management programs relying on these control practices.
- Simplified models were developed during this research to calculate sediment scour in catchbasin sumps. These can be implemented in stormwater management software packages, such as WinSLAMM, to calculate the expected sediment scour.

Methodology and Description of Experiment

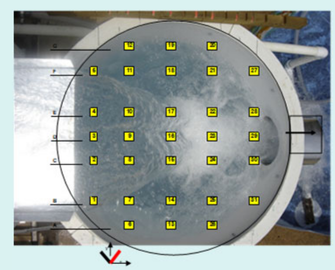
- The full-scale physical model was based on the optimal catchbasin geometry recommended by Lager, *et al.* (1977), and tested by Pitt 1979; 1985; and 1993. Water is re-circulated during the test.
- Two different evaluations were performed:
  - ✓Hydrodynamics: Velocity measurements (Vx, Vy, and Vz)
  - ✓Scour: Sediment scour at different overlying water depths and flow rates, and for different sediment characteristics



Hydrodynamic Tests

(Methodology and Description of Experiment)

- Two inlet geometries: Rectangular (50 cm wide), and Circular (30 cm diameter).
- Three flow rates: 10, 5, and 2.5 LPS (160, 80, and 40 GPM).
- Velocity measurements (Vx, Vy, and Vz).
- Five overlaying water depths: 16, 36, 56, 76, and 96 cm above the sediment.



- Water was re-circulated during the test.
- Total points per test: 155
- 30 rapid velocity measurements at each point
- Instrument: Acoustic Doppler Velocity Meter (ADV) - Flowtraker

Scour Tests

(Methodology and Description of Experiment)

Type of Sediment	Flow rate (L/s)	Water depth over sediment (cm)	Duration (min)	Sampling (Composite samples)
Mixture	0.3, 1.3, 3.0, 6.3, and 10	10	25 min for each flow rate	First 5-min, and next 20-min for each flow rate. Inlet samples for each elevation.
		25		
		46		
		106		
	10	10	4 impacts with prolonged flow of 3 min each	One composite sample for each impact
		25		
		46		
		106		
Homo-geneous	10	24	30 min for each elevation	3-min composite samples at influent and effluent.
		35		

- Once through test using lake water.
- The pool traps the scoured sediment before the water discharges back to the lake.

- The scour tests were performed with a 50-cm wide rectangular inlet.

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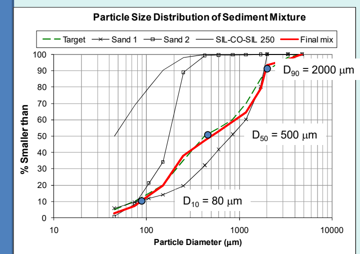
Scour Tests

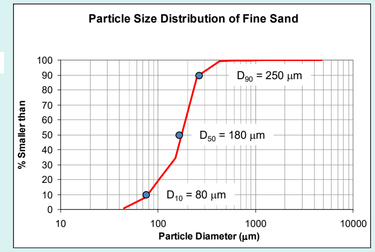
(Methodology and Description of Experiment)

- **Sediment mixture** (D_{50} = 500 µm; uniformity coefficient = 11) based on PSD found by Pitt (1997), Valiron and Tabuchi (1992), and Pitt and Khambhammuttu (2006)



Develops armoring layer

- **Sediment with homogeneous particle size** (D_{50} = 180 µm; uniformity coefficient = 2.5)



Only a minimal armoring layer developed. Data also used for CFD calibration and validation.

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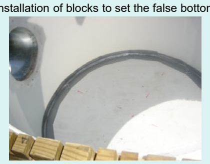
Scour Tests

Installation of blocks to set the false bottom

Measuring depth below the outlet (overlaying water depth above sediment)

Cone splitter and sample bottles



False bottom sealed on the border

Leveling of sediment bed: 20 cm thick

Performing scour test

Sieve analysis

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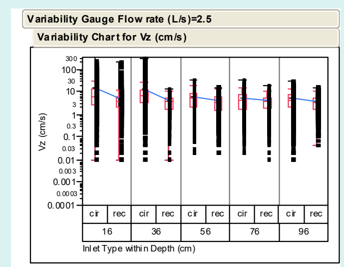
Experimental Results - Hydrodynamics

Effect of Inlet Type



45 two-sample t-tests
p-values < 0.001

- The inlet geometry affects the magnitude of the impacting energy of the plunging water jet.
- The impact of a circular plunging jet is concentrated and the flow rate per unit width is greater than with a rectangular jet.
- Circular plunging jets affect sediments under deeper water layers than rectangular jets.

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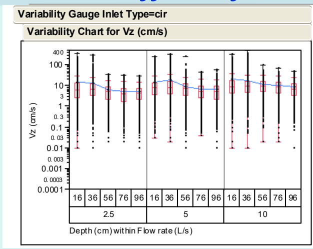
Experimental Results - Hydrodynamics

Effect of Overlaying Water Depth



- One-way ANOVA tests with paired comparisons.
- Analysis for Vx, Vy, and Vz

p-values < 0.001

t	Alpha	
1.96047	0.05	
Level		**Mean**
16	A	5.8443011
56	B	3.9970000
76	B	3.9950538
36	B	3.8961935
96	B	3.8293011

t	Alpha	
1.96047	0.05	
Level		**Mean**
16	A	21.314613
36	B	17.157398
56	C	10.854871
76	C	10.246602
96	C	8.644839

Lowest impacting energy scenario: Rectangular inlet and 2.5 L/s flow rate

Highest impacting energy scenario: Circular inlet and 10 L/s flow rate

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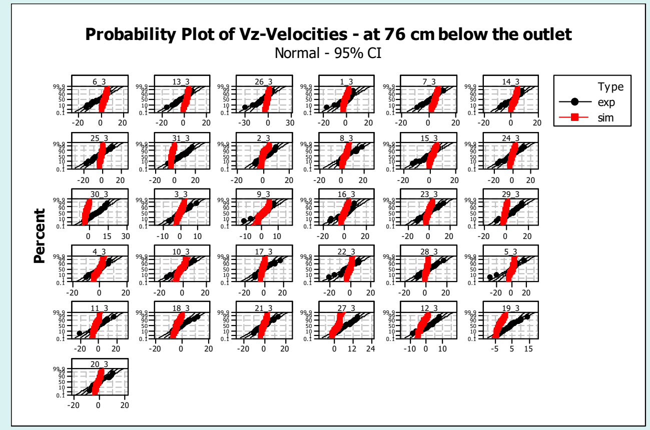
CFD Modeling

Calibration of Hydrodynamics – 3D-Model



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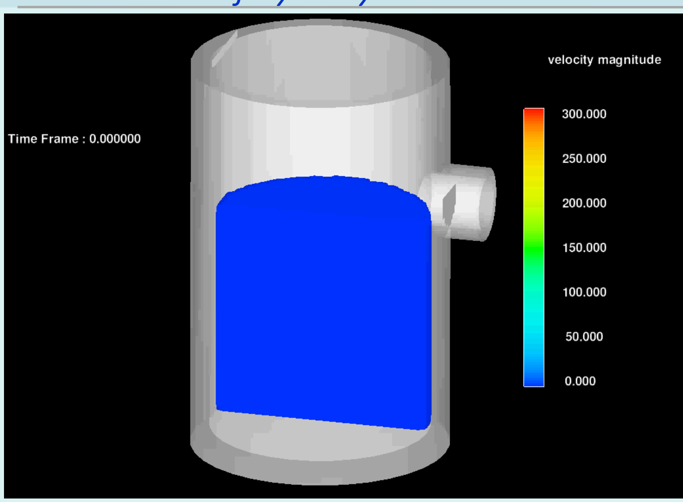
CFD Modeling - Velocities

Calibration of Hydrodynamics – 3D-Model



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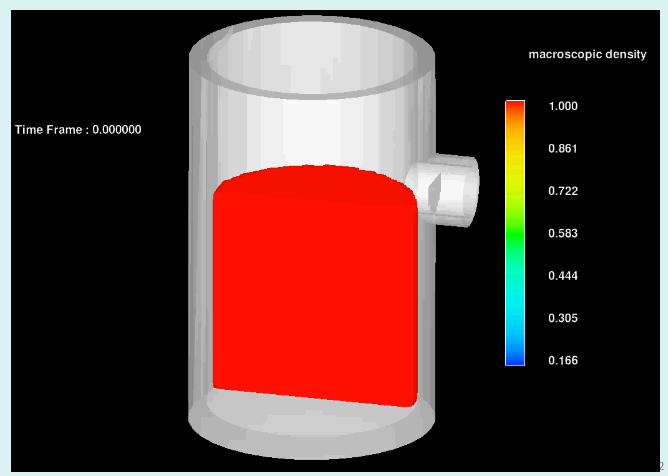
CFD Modeling – Air Entrainment

Calibration of Hydrodynamics – 3D-Model



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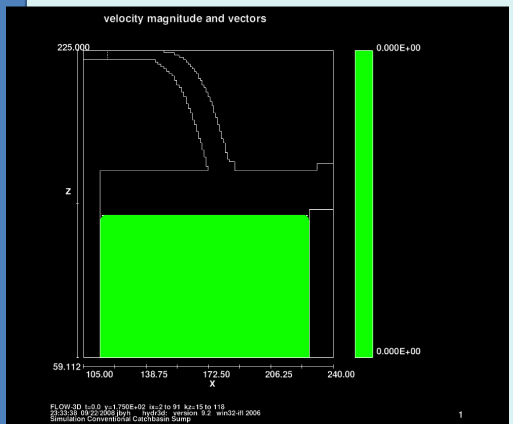
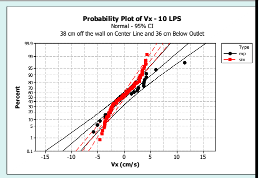
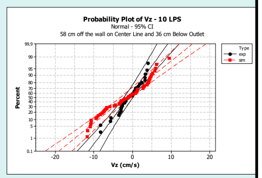
CFD Modeling

Calibration and Validation of Hydrodynamics – 2D-Model







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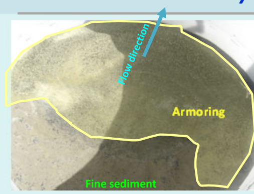
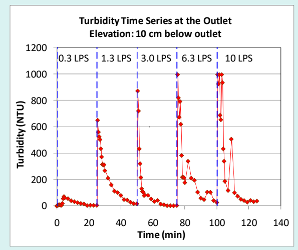
Sediment Scour Tests with Sediment Mixture

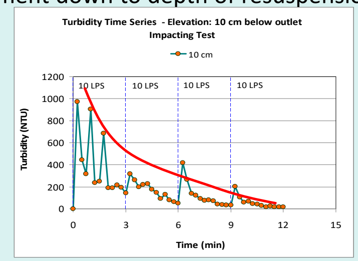
Armoring Effect



- An exponential decay pattern was found in the turbidity time series for each flow rate at steady conditions.
- "Washing machine" effect (resuspension of surface layer and flushing out of finer sediment down to depth of resuspension)



Continuous flow rate



Fluctuating flow rate

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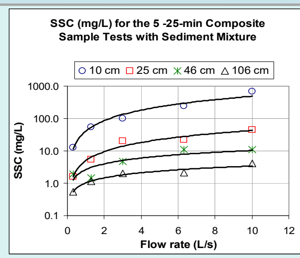
Experimental Results – Sediment Mixture

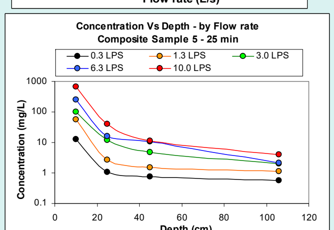
Total SSC (mg/L) of scoured sediment for the 0 - 5-min composite samples.

Overlaying water depth (cm)	Flow rate (L/s) 0.3	1.3	3.0	6.3	10.0
	SSC (mg/L)				
10	56	392	427	1045	1139
25	7.0	8.0	42	108	46
46	5.0	4.1	6.5	12	11
106	1.7	2.6	3.3	2.9	1.7

Total SSC (mg/L) of scoured sediment for the 5 - 25-min composite samples.

Overlaying water depth (cm)	Flow rate (L/s) 0.3	1.3	3.0	6.3	10.0
	SSC (mg/L)				
10	12.6	55	102	244	684
25	1.6	5.5	20	22	44
46	2.0	1.5	4.8	11	12
106	0.6	1.1	2.0	2.1	4.0





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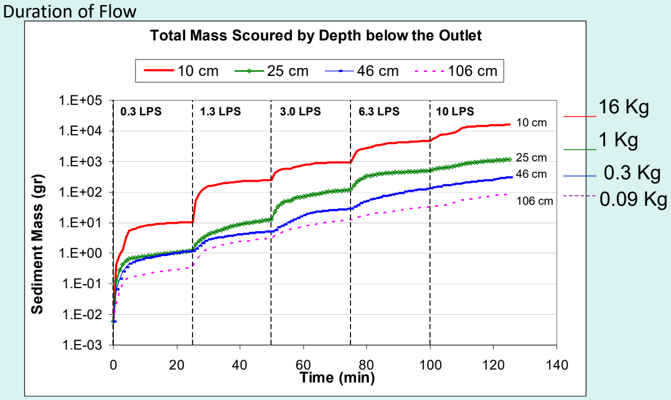
Experimental Results – Sediment Mixture

Total Sediment Mass Loss

Total Mass Scoured Plotted vs. Overlaying Water Depth above the Sediment Bed and Duration of Flow



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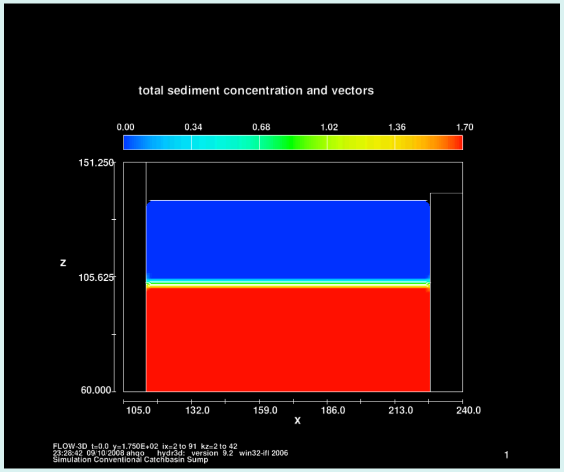
CFD-Customized Scour Model Calibration



Colors represent sediment concentration (g/cm³)

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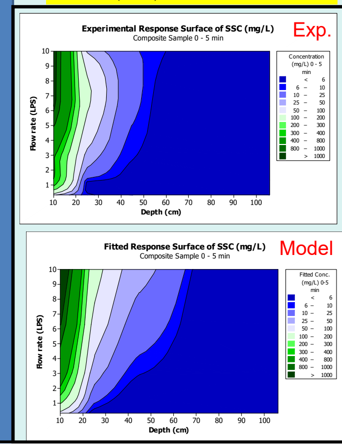
Scour Response Surfaces (SSC, mg/L): *Sediment Mixture*

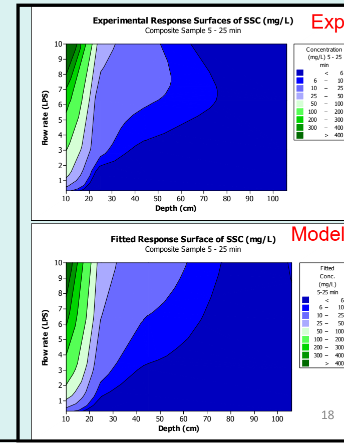
0-5 min composite samples

$$SSC = (670)^2 \cdot H^{-3.32} \cdot Q^{\left(0.92H^{-0.15}\right)}$$



5-25 min composite samples

$$SSC = (115)^2 \cdot H^3 \cdot [\ln(H)]^{-15} Q^{\left(1.6H^{-0.19}\right)}$$



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Scour Response Surfaces (SSC, mg/L): *Sediment Mixture*

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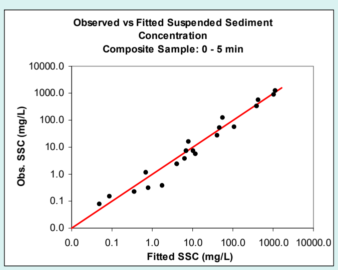

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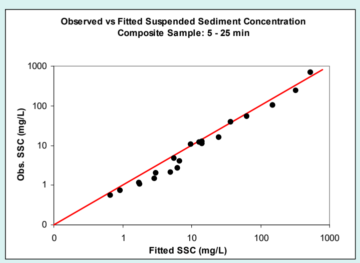

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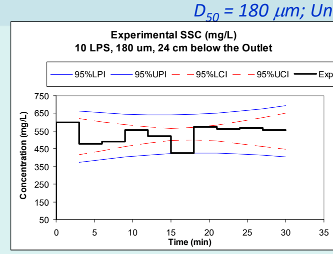
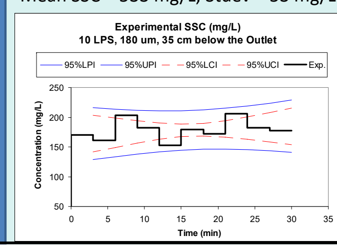
Experimental Results – Sediment Scour

Sediment with Homogeneous Particle Size:
D_{50} = 180 µm; Uniformity Coefficient = 2.5



p-value: 0.6 (Constant SSC concentration), Mean SSC = 533 mg/L, Stdev = 53 mg/L



- Absence of an armoring layer causes continuous exposure of the sediment at the surface of the sediment layer (little change in scoured sediment concentration with time).
- Scour rate will decrease only when the overlaying water depth is large enough (hole) to reduce the acting shear stress.

p-values: 0.5 (Constant SSC concentration)
Mean SSC = 178 mg/L
Standard deviation = 16 mg/L

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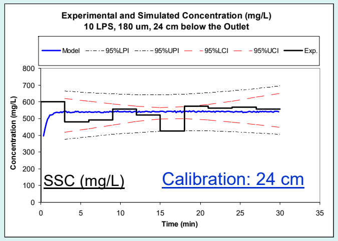
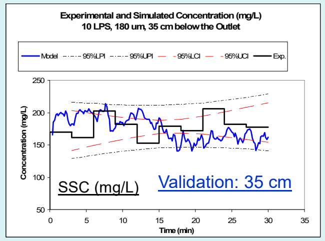
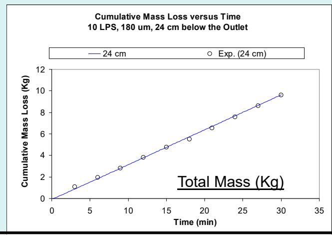
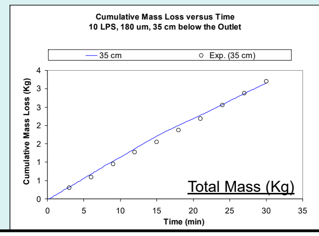
CFD-Customized Scour Model Calibration and Validation

Homogeneous sediment of 180 μm, 10 L/s flow rate









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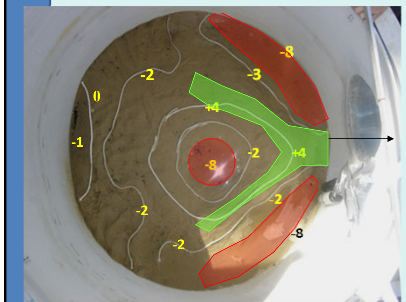
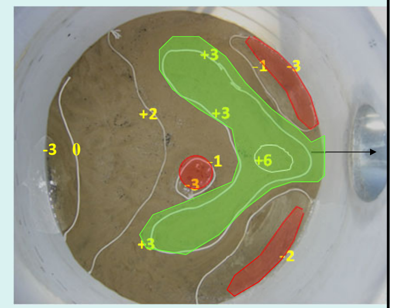
Experimental Results – Sediment Scour

Sediment with Homogeneous Particle Size: D50 = 180 μm



24 cm overlaying water depth above the sediment layer.



35 cm overlaying water depth above the sediment layer.

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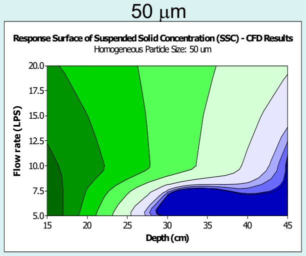
Scour Response Surfaces (SSC, mg/L):

Sediment with Homogeneous Particle Size

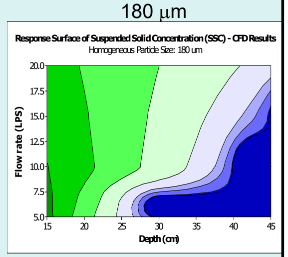
SSC (mg/L):

	<	6
6	–	10
10	–	50
50	–	100
100	–	250
250	–	500
500	–	750
750	–	1000
1000	–	1250
	>	1250

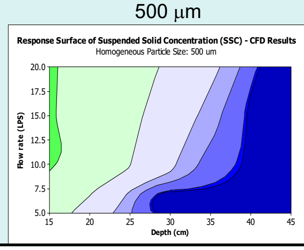
50 μm



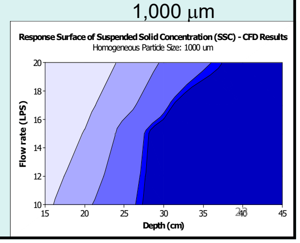
180 μm



500 μm



1,000 μm



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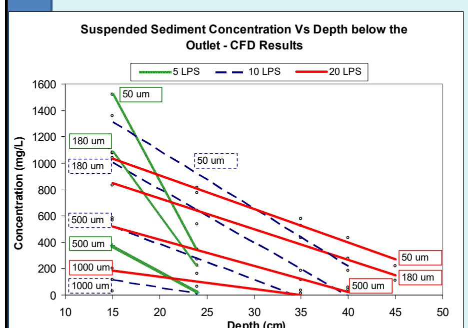
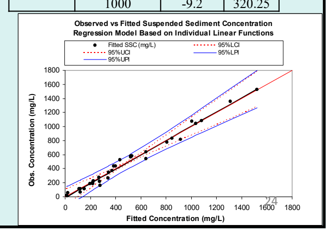
Scour Response Surfaces (SSC, mg/L):

Sediment with Homogeneous Particle Size



$$SSC = m_{Q,D} \cdot H + b_{Q,D}$$

	Diameter (μm)	m	b
5 L/s	50	-130.47	3479
	180	-95.43	2513.7
	500	-39.9	973
10 L/s	50	-43.7	1966
	180	-40.45	1612.1
	500	-26.74	920.6
	1000	-11.05	279.4
20 L/s	50	-25.43	1418.1
	180	-23.2	1196.7
	500	-17.83	771.35
	1000	-9.2	320.25



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Conclusions

- The overlaying water depth above the sediment is highly important in protecting the sediment from scour. SSC decreases with an exponential pattern as the overlaying water depth increases for a sediment mixture (with armoring), and with a linear pattern for sediment with a homogeneous particle size.

- The inlet geometry has a significant effect on the scour potential of sediments captured in conventional catchbasin sumps. Modifying the inlet flow to decrease the impacting energy and/or physically isolating the sediment from the impacting water provides a feasible alternative on catchbasins already installed .

- It is recommended to perform scour tests with fluctuating flow rates to account for the flow variability that actually occurs during rainfall events

- The scour response surface equations can be implemented in stormwater management software packages to calculate the loss of sediment scoured from catchbasin sumps and similar devices.