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B.S. Engineering Science, Humboldt State University, Arcata, CA 1970.
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Ph.D., Environmental Engineering, University of Wisconsin, Madison, WI 1987.

More than 45 years working in the area of urban water and wet weather flows, focusing on the effects, sources, and control of stormwater. About 100 publications, including several books.

Stormwater Particulate Pollutant Strengths

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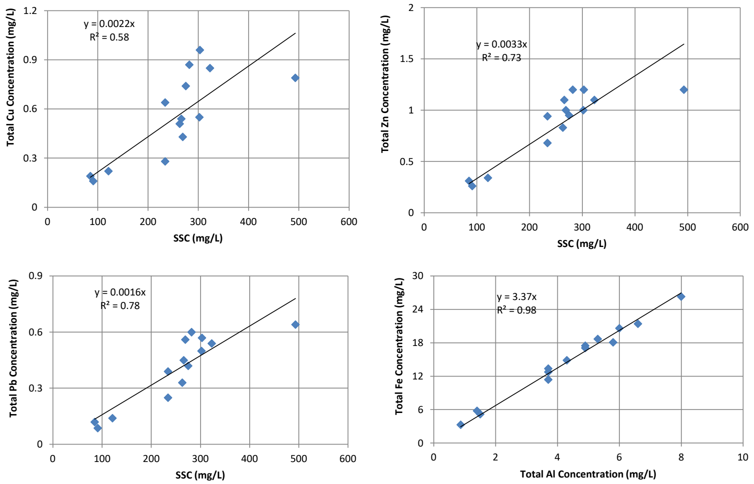
Presentation Topics

- Pollutant strength calculations
- Analytical schemes to determine pollutant characteristics of stormwater particle size ranges
- Settling and scour of stormwater particulates
- Pollutant strengths by particle size
- Pollutant strengths by particle size and treatability observations
- Conclusions

- Pollutant strengths are the contaminant concentrations associated with the particulate matter in the stormwater.
- Particulate strengths are determined by calculating the pollutant concentration only associated with the particulates (measured as TSS or SSC, depending on how the sample was collected and analyzed) in the runoff water.
- They are calculated by the following equation, and are usually expressed as mg pollutant/kg solids:

$$\frac{(\boldsymbol{total\ conc.} - \boldsymbol{filterable\ conc.})}{\boldsymbol{particulate\ solids\ conc.}}$$

Examples of Metal Associations with Stormwater Particulates (and one example for Fe and Al associations) for an Industrial Site



Regression equations and coefficients are all significant based on ANOVA analyses

Example Stormwater Particulate Strengths from Different Residential and Commercial Source Areas (bulk samples)

Mean values from several studies	Copper (mg Cu/kg SS)	Lead (mg Pb/kg SS)	Zinc (mg Zn/kg SS)	Chromium (mg Cr/kg SS)
Resid./Commer. road shoulder	35	230	120	25
Residential streets	39	87	350	11
Resid./Commer. pvd sidewalk	44	1200	430	32
Resid./Commer. unpvd parking	45	160	170	20
Paved driveways	89	240	650	11
Resid./Commer. roofs	130	980	1,900	77
Resid./Commer. pvd parking	145	630	420	47
Residential roofs	160	870	2,900	n/a
Resid./Comer. pvd driveways	170	900	800	70
Street Dirt Residential	230	1,615	431	81
Residential NSQD outfalls	431	358	1,262	n/a

The coefficients of variation (COV, standard deviation/mean concentrations) ranged from about 0.75 to 1.5 for these data.

Fugacity Modeling

- Fugacity equilibrium models (several levels available) (Mackay et al. 1992) were used for predicting the phase partitioning of selected PAHs for comparison with observed partitioning.
- Equations used in the fugacity Level 1 modeling included:

$$\text{Fugacity, } f = \frac{M}{\sum(V_i * Z_i)}$$

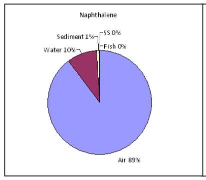
Where, Z_i = fugacity capacities of air, water, sediment, SS, and fish for i =1, 2, 3, 4, and 5 respectively

$$Z_1 = \frac{1}{RT} \qquad Z_2 = \frac{1}{H} \qquad Z_3 = Z_2 * P_3 * \phi_3 * \frac{K_{OC}}{1000} \qquad Z_4 = Z_2 * P_4 * \phi_4 * \frac{K_{OC}}{1000} \qquad Z_5 = Z_2 * P_5 * L * \frac{K_{OW}}{1000}$$

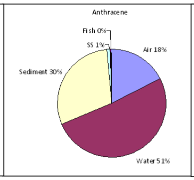
Where, R = gas constant (8.314 J/mol K), T = absolute temperature (K), H= Henry's law constant (Pa.m3/mol), K_{OC} = Organic-water partition coefficient, K_{OW} = Octonal-water partition coefficient, P = density of phase (kg/m3), Ø= organic fraction of in the phase, L= Lipid content of fish.

Fugacity Modeling

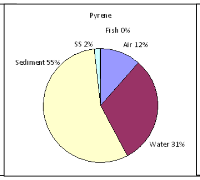
- Model predications indicated that high molecular weight PAHs are predominately partitioned with sediments, while low molecular weight PAHs are predominant in the air and water phases. Most of the 13 PAHs investigated during this study were HMW PAHs and therefore more associated with particulates.
- HMW PAHs indicate pyrogenic (combustion) sources.
- LMW PAHs indicate petrogenic (oil) sources.



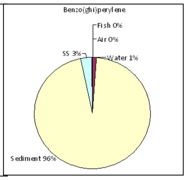
Molecular Weight: 128



Molecular Weight: 178



Molecular Weight: 202



Molecular Weight: 276

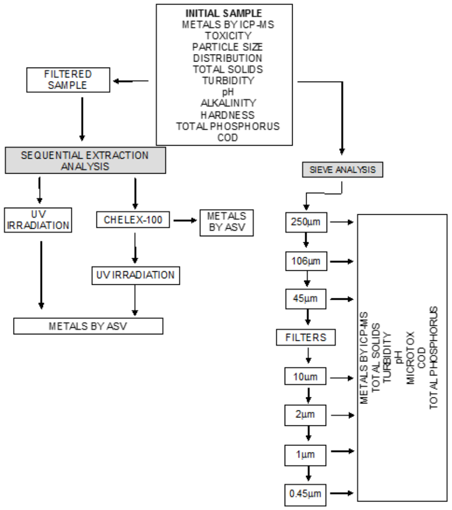
PAH Associations with Stormwater Particulates (MCTT Treatability Tasks)

PAH	% Association	
	Water	Particulate Matter
Naphthalene	22	78
Fluorene	3	97
Phenanthrene	2	99
Anthracene	8	92
Fluoranthene	29	71
Pyrene	19	81
Benzo(a)anthracene	3	99
Chrysene	1	99
Benzo(b)fluoranthene	1	99
Benzo(k)fluoranthene	2	98
Benzo(ghi)perylene	1	99
Benzo(a) pyrene	1	99

The fugacity modeling generally under-predicted the particulate bound fractions, but was very useful in identifying significant factors affecting the partitioning.

Analytical Schemes to Determine Pollutant Characteristics of Stormwater Particle Size Ranges

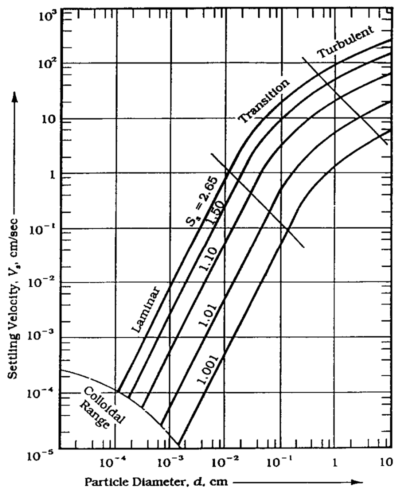
Analytical scheme used by Morquecho to determine pollutant associations with particle size, colloids, and organic complexes (samples always split using USGS/Decaport cone splitter)



Filterable forms of the metals determine their ability to be removed using ion exchange or sorption methods (higher valence ionic forms easiest to remove, large organic-metal complexes are difficult to remove)

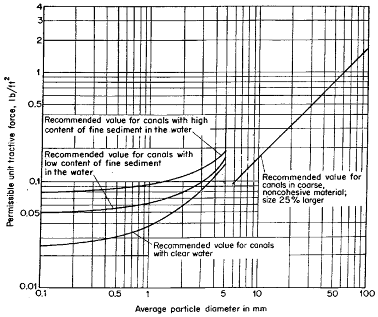
	Filterable metal percentage in ionic forms	Filterable metal percentage bound in organic complexes
Zinc	15	85
Copper	70	30
Cadmium	10	90
Lead	12	88

Settling and Scour of Stormwater Particulates



Settling velocity of discrete particulates as a function of size and specific gravity (Reynolds and Richards 1996)

Traditional methods can be used to calculate settleability of stormwater particulates and scour of previously settled material.



Erodibility of previously settled material based on size and shear stresses (Chow 1959)

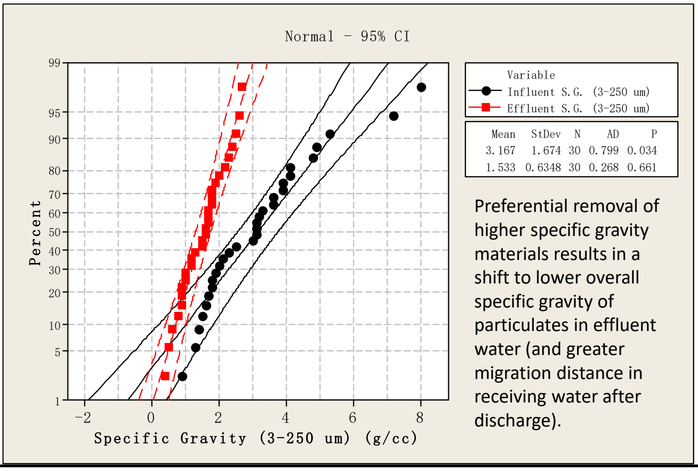
Specific Gravity and Volatile Solids of Sediment Collected from Stormwater Treatment Device

Sieve size range (um)	Average Specific Gravity (g/cc)	Average Volatile Solids (%)
Sticks	0.84	81.2
>2800	0.66	70.9
1400 - 2800	1.15	57.8
710-1400	1.43	42.7
355-710	2.56	26.1
180-355	2.76	19.4
75-180	2.97	20.6
45-75	3.30	25.7
<45 (Pan)	3.46	26.0

Specific gravity decreases as the volatile solids content increases; larger particle sizes have lower specific gravity and greater volatile solids as they contain larger amounts of light-weight organic debris for these industrial area stormwater sediment samples. Their settling rates are still large due to their large sizes.

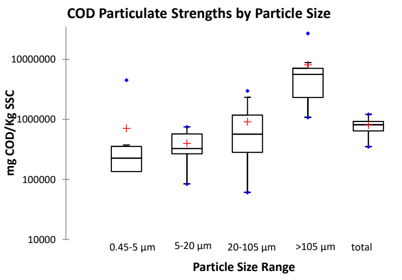
Changes in Specific Gravity with Sedimentation Treatment at an Industrial Site

Influent: 5th to 95th percentile, 1.3 to 6 g/cc (median: 3.2 g/cc)
Effluent: 5th to 95th percentile, 0.5 to 2.3 g/cc (median: 1.5 g/cc)

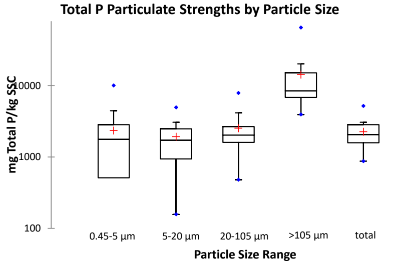


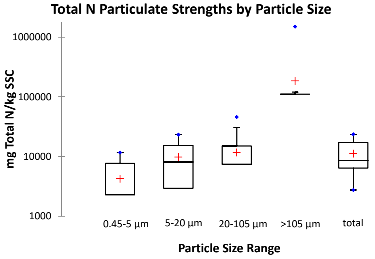
Preferential removal of higher specific gravity materials results in a shift to lower overall specific gravity of particulates in effluent water (and greater migration distance in receiving water after discharge).

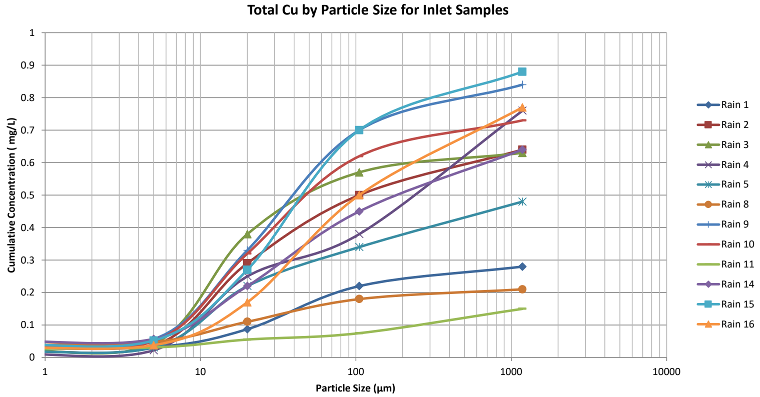
Pollutant Strengths by Particle Size


COD Particulate Strengths by Particle Size

COD, phosphorus, and nitrogen particulate strengths are greatest for the large particles (mostly organic material for these larger particle size ranges).

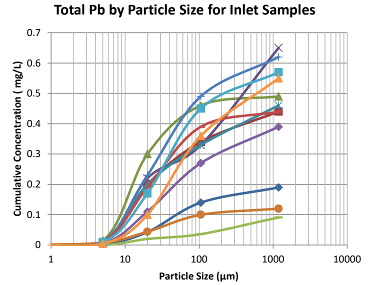

Total P Particulate Strengths by Particle Size

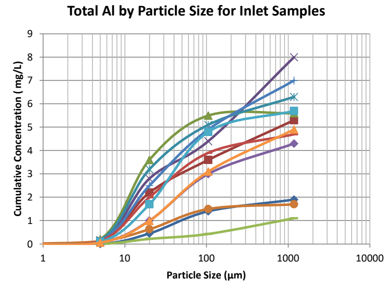

Total N Particulate Strengths by Particle Size

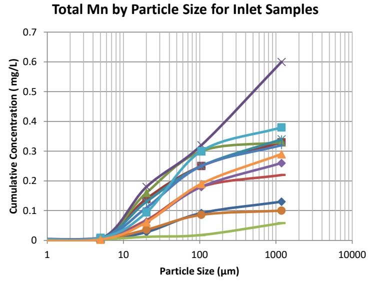

Total Cu by Particle Size for Inlet Samples

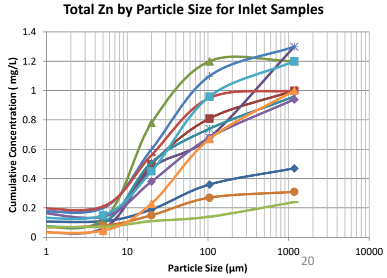
The majority of the copper concentrations (and mass) are associated with the 10 to 300 µm particle size range in these industrial area samples. Necessary to remove particulates down to about 10 micrometers to remove most of the particulate-bound copper.

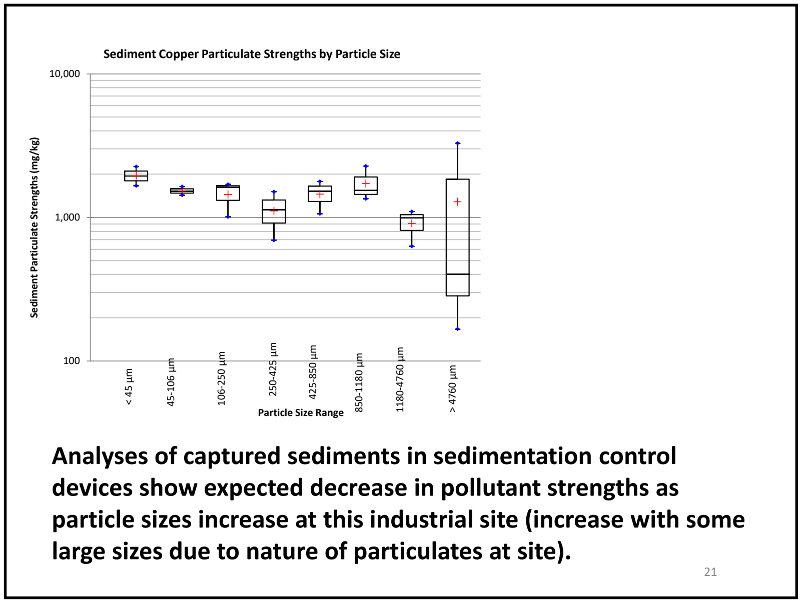
Similar results for other metals:


Total Pb by Particle Size for Inlet Samples


Total Al by Particle Size for Inlet Samples

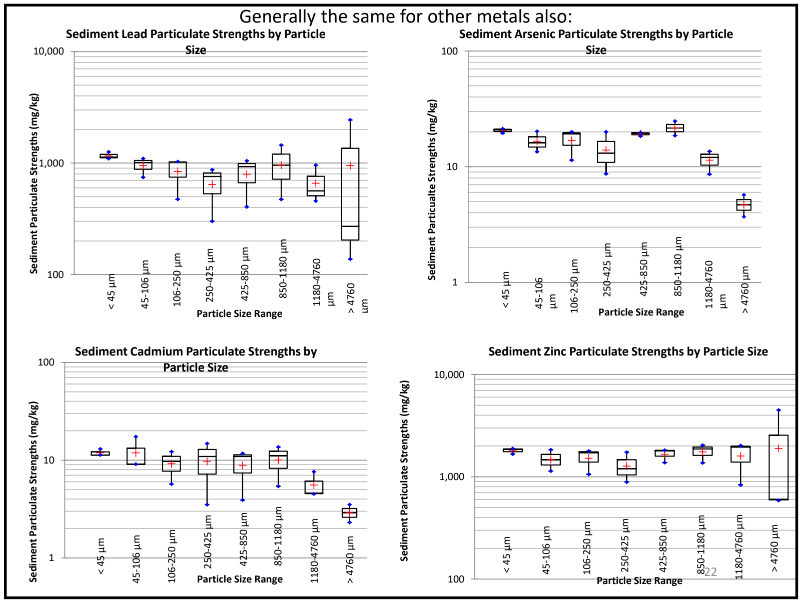

Total Mn by Particle Size for Inlet Samples


Total Zn by Particle Size for Inlet Samples



Sediment Copper Particulate Strengths by Particle Size

Analyses of captured sediments in sedimentation control devices show expected decrease in pollutant strengths as particle sizes increase at this industrial site (increase with some large sizes due to nature of particulates at site).



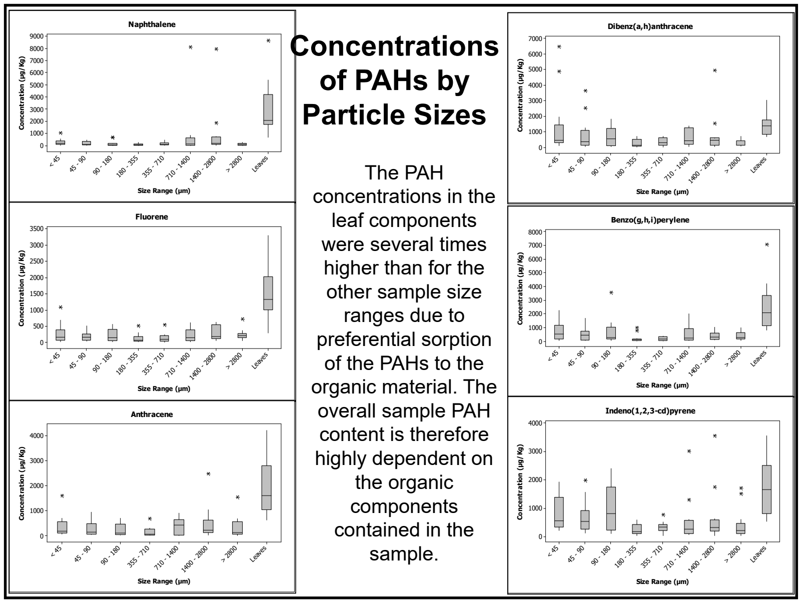
Generally the same for other metals also:

Sediment Lead Particulate Strengths by Particle Size

Sediment Arsenic Particulate Strengths by Particle Size

Sediment Cadmium Particulate Strengths by Particle Size

Sediment Zinc Particulate Strengths by Particle Size



Concentrations of PAHs by Particle Sizes

The PAH concentrations in the leaf components were several times higher than for the other sample size ranges due to preferential sorption of the PAHs to the organic material. The overall sample PAH content is therefore highly dependent on the organic components contained in the sample.

Naphthalene

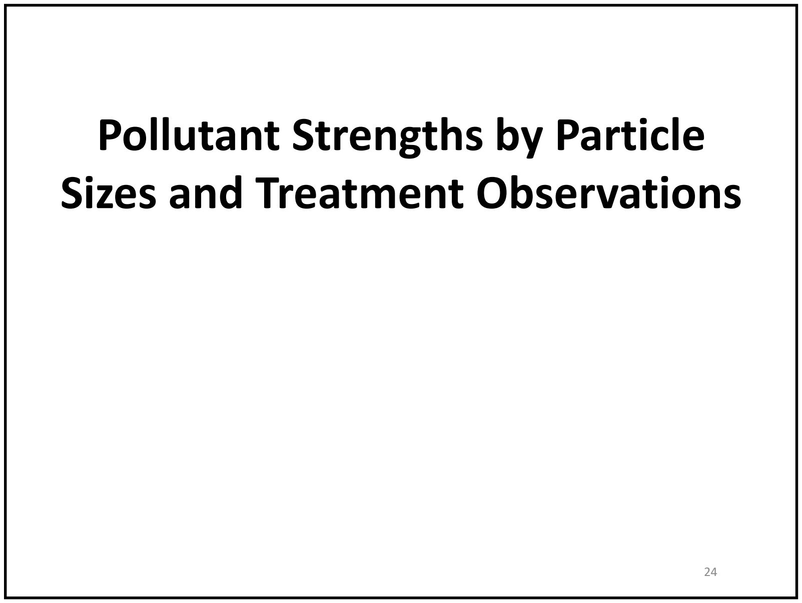
Fluorene

Anthracene

Dibenz(a,h)anthracene

Benzo(g,h,i)perylene

Indeno(1,2,3-cd)pyrene

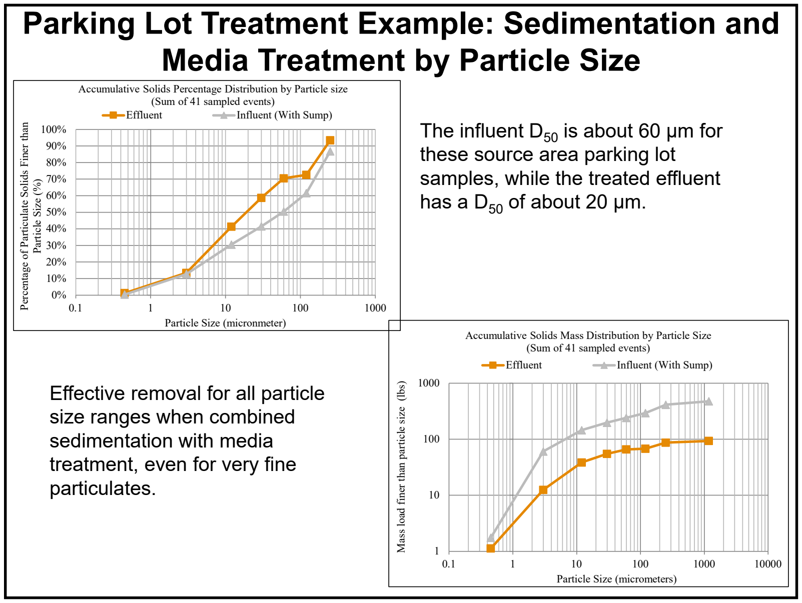


Pollutant Strengths by Particle Sizes and Treatment Observations

Residential and commercial area example: Average percent reduction in pollutant discharges after controlling down to indicated particle size:

	250 µm	45 µm	10 µm	2 µm	0.45 µm
Suspended Solids	22	71	95	94	100
Turbidity	23	41	72	77	86
COD	0	23	36	37	40
Total Phosphorus	12	32	48	51	52
Zinc	2	15	23	30	31
Copper	4	14	34	30	36
Cadmium	0	8	0.1	0.1	7
Lead	3	21	23	23	24

For these samples, the control of filterable pollutants (using chemical precipitation, ion exchange or sorption, for example) is also necessary for high levels of control. Control down to about 35 µm (removal of all particulates larger than this size) can result in about 80% TSS reductions (a common goal), but that would only result in about <25 to 50% control of total forms of other stormwater pollutants (probably lower than desired).



Parking Lot Treatment Example: Sedimentation and Media Treatment by Particle Size

The influent D_{50} is about 60 µm for these source area parking lot samples, while the treated effluent has a D_{50} of about 20 µm.

Effective removal for all particle size ranges when combined sedimentation with media treatment, even for very fine particulates.

Conclusions

- Knowing the distribution of pollutants associated with different sized stormwater particles allows more accurate determinations of their sources, transport, and control.
- Urban stormwater quality models can use this information when routing stormwater particulate-bound pollutants from their source areas and then through the drainage system and stormwater controls.
- The discharged particle size distributions and associated pollutants can then be used in receiving water models to calculate their fates and effects.