SIMPTM Diagnosis

A technique for accurate urban runoff load estimation

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Three of the greatest technical challenges associated with developing a total maximum daily load (TMDL) are

- accurately quantifying the stormwater pollutant levels entering a particular waterway in any given year,
- developing specific actions to significantly reduce these pollutant loadings, and
- accurately predicting how often these actions must occur to get the most cost-effective results.

Pacific Water Resources Inc. (Beaverton, Ore.) has developed a load estimation procedure that can quantify urban pollutant loadings and accurately estimate optimum cleaning practices for streets and catch basins. Rather than monitoring stormwater quality, the procedure involves monitoring sediment ("street dirt") in pilot-test areas that are representative of the watershed's various land uses, analyzing the sediment's physical and chemical characteristics, and using the data in the **sim**plified **p**articulate **t**ransport **m**odel (SIMPTM) to evaluate various cleaning practices based on an average rainfall

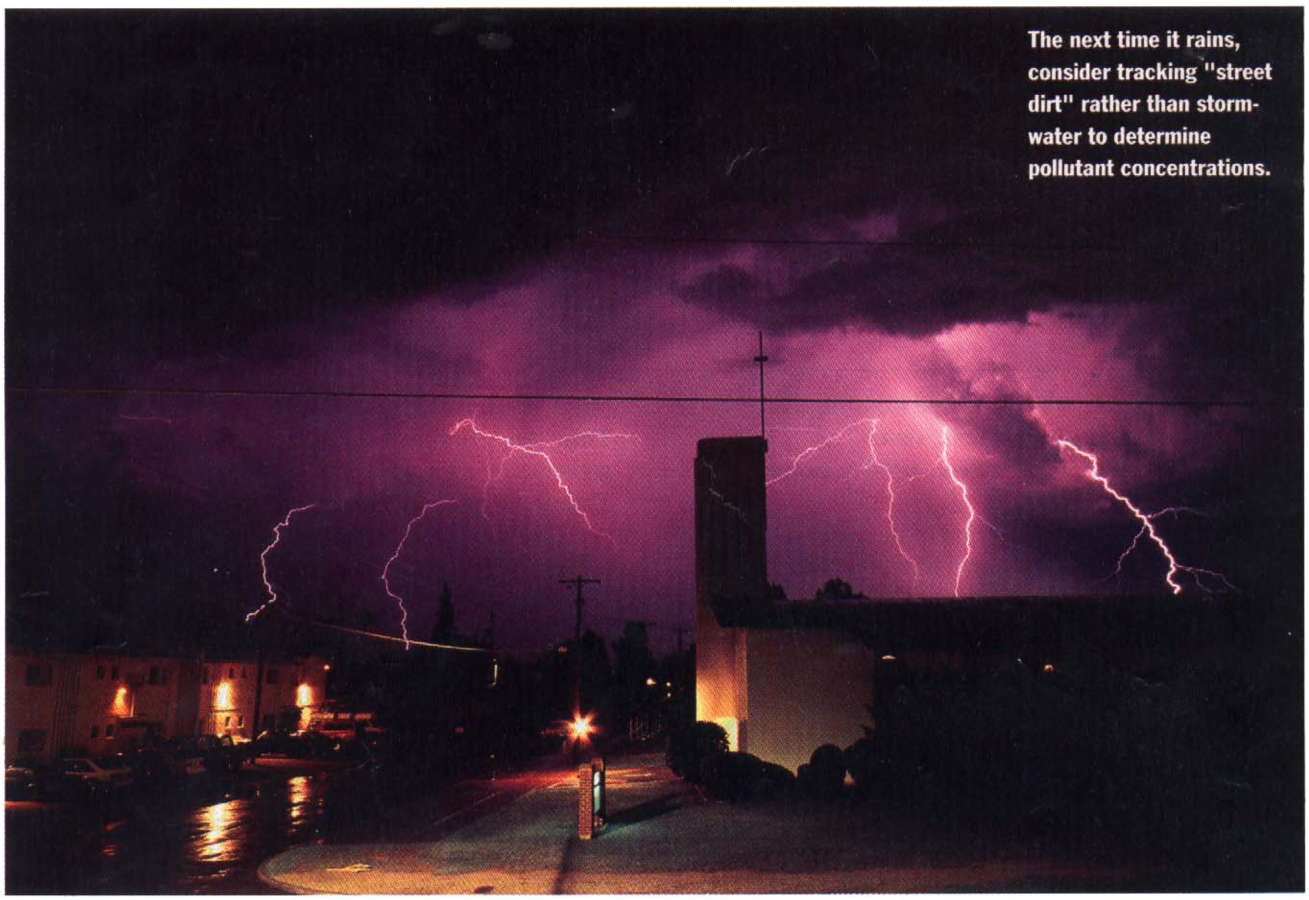


Table 1. Observed Mean Particle Size (PS) Fraction of Accumulated Sediments (in µm)

Land Use/Site Name	Test Area	Type	PS1 <63	PS2 63–125	PS3 125–250	PS4 250–600	PS5 600–1,000	PS6 1,000–2,000	PS7 2,000–6,370	PS8 >6,370
PROJECT: LIVONIA										
Shopping center commercial Newburgh	1	Parking Lot	0.032	0.082	0.216	0.244	0.166	0.144	0.099	0.017
Recreational area parking Fox Creek	2A	Parking Lot	0.037	0.055	0.093	0.199	0.204	0.333	0.077	0.002
Single-family residential Munger	15	Street	0.085	0.113	0.221	0.294	0.095	0.095	0.079	0.018
Single-family residential Riverside	20	Street	0.079	0.140	0.271	0.221	0.084	0.093	0.081	0.031
Overall project average			**0.058**	**0.098**	**0.200**	**0.240**	**0.137**	**0.166**	**0.084**	**0.017**
PROJECT: JACKSON										
Single-family residential Durand	1	Street	0.023	0.051	0.143	0.270	0.140	0.107	0.192	0.073
Single-family residential Jackson	2	Street	0.057	0.105	0.218	0.340	0.086	0.072	0.096	0.025
Central business District Cortland	3	Street	0.030	0.063	0.154	0.337	0.134	0.112	0.132	0.038
Highway Parnell	4	Street	0.025	0.043	0.139	0.271	0.103	0.142	0.218	0.058
Industrial Carroll	5	Street	0.029	0.050	0.162	0.216	0.129	0.134	0.218	0.062
Single-family residential Seymour	6	Street	0.031	0.059	0.171	0.338	0.137	0.090	0.123	0.051
Overall project average			**0.033**	**0.062**	**0.164**	**0.295**	**0.122**	**0.110**	**0.163**	**0.051**

year. ("Street dirt" is widely believed to be the primary source of pollutants in urban stormwater runoff.)

This procedure recently was used in projects in two Michigan watersheds:

- the City of Livonia's portion of the Bell Branch and Tarabusi Creek Subwatershed of the Rouge River in southeastern Michigan, and
- the City of Jackson and Jackson County's portion of the Grand River in southwestern Michigan.

Test Areas

First, the project teams had to select pilot-test areas that best represented the region's predominant land use and physical characteristics. They gathered the best available topography data and information on the location of various storm sewer systems, including catch basins, pipes, and outfalls, to delineate small drainage subareas. Then they surveyed these subareas via automobile to gather more data on land use and physical characteristics. These data ordinarily include the type of surface drainage system (curb and gutter, roadside swales, etc.), street pavement condition and texture, slope along the upland stormwater flow path, whether direct connections between roof drains and gutter line exist, and average dimensions of any sediment traps (catch basins) in stormwater inlets.

In the Livonia study, the team chose four pilot-test areas: a commercial shopping center (Newburgh), two single-family residential areas (Munger and Riverside), and a recreational area (Fox Creek). Each test area was relatively small, with between 7 and 14 catch basins. The monitoring sites in these areas ranged from 55.7 to 139 m^2 (600 to 1500 ft^2) and included a shopping center parking

Table 2. Chemical Analysis Parameters and Test Methods

USEPA Parameter	Detection Method	SPLP Detection Limit (ppm)	Limit (ppm)
Total Phosphorus	365.3	0.2	-
Chem. O2 Demand	410.1	1.0	-
Chloride	300	0.1	-
Arsenic	7060A	1.0	0.05
Barium	6010	1.0	0.01
Cadmium	7131A	0.05	0.02
Chromium	6010	2.5	0.05
Lead	6010	1.0	-
Mercury	7471A	0.1	-
Selenium	7740	0.5	-
Silver	7761	0.5	0.02
Copper	6010	1.0	0.01
Zinc	6010	1.0	0.05

lot, two residential streets, and a golf course parking lot that fed directly into a stormwater inlet (catch basin).

In the Jackson study, the team chose six pilot-test areas: three single-family residential areas (Durand, Jackson, and Seymour), one downtown commercial site (Cortland), one industrial site (Carroll), and one highway site (Parnell). The areas ranged from 29.7 to 84.5 m^2 (320 to 910 ft^2), and each was a paved street directly tributary to one catch basin.

Sample Collection

In the Livonia study, the project team collected initial samples of street and parking lot dirt (via industrial vacuum) and catch-basin sediments (via soil sampler and shovel) in mid-September 1999. Then, all paved surfaces were swept and all catch-basin sumps and laterals were cleaned by city staff in early October. Street sweeping was supposed to be suspended for these areas during the monitoring period (early October 1999 through May 2000), but two unscheduled sweepings occurred and were factored into the analysis.

Team members monitored street and parking lot dirt accumulations on Nov. 4, 1999; Jan. 6, 2000; March 24, 2000; and May 16, 2000. They monitored a second site in each test area on March 24, 2000, and then monitored both sites in the two residential areas on May 16, 2000. The team also monitored sediment accumulations in catch-basin sumps on Nov. 5, 1999; Dec. 12, 1999; March 24, 2000; and May 11, 2000.

In the Jackson study, the project team collected initial samples of street dirt and catch-basin sediments at all six sites in early April 2000. Then, catch-basin sumps and laterals were cleaned by city and county staff in mid-April, and street sweeping was suspended for these areas during the monitoring period (mid-April through mid-September 2000). The team monitored street and catch-basin accumulations on May 4, June 8, July 11, Aug. 9, and Sept. 6, 2000.

Physical Analysis

The project teams analyzed sediment grain size and used the results to calibrate the SIMPTM model (see Table 1, p. 60). On average, the greatest fraction (approximately 24% to 30%) was in the 250 to 600 µm range, which runoff can rarely transport. Instead, particles this size and larger typically impede the transport of smaller particles

Table 3. Average Mass Fraction or Pollutant Potency by Composited Particle Group

	Jackson, MI			Livonia, MI			Portland, OR		
Parameter	Fine (ppm)	Med. (ppm)	Coarse (ppm)	Fine (ppm)	Med. (ppm)	Coarse (ppm)	Fine (ppm)	Med. (ppm)	Coarse (ppm)
Total Phosphorus	0.9	0.8	0.7	22.3	31.5	26.6	NT	NT	NT
Chem. O2 Demand	140.7	49.4	549.9	5,735	7,501	6,312	144,444	153,909	345,833
Chloride	239.0	73.7	89.2	NT	NT	NT	NT	NT	NT
Arsenic	4.9	2.7	3.8	5.2	3.3	3.7	3	4	1
Arsenic (SPLP)	ND	ND	ND	NT	NT	NT	NT	NT	NT
Barium	124.4	60.7	45.3	67.0	98.0	62.4	330	362	322
Barium (SPLP)	ND	ND	ND	NT	NT	NT	NT	NT	NT
Cadmium	1.0	0.4	0.2	1.3	0.8	0.8	2	4	1
Cadmium (SPLP)	ND	ND	ND	NT	NT	NT	NT	NT	NT
Chromium	45.2	31.3	60.6	78.1	51.1	60.4	74	83	32
Chromium (SPLP)	ND	ND	ND	NT	NT	NT	NT	NT	NT
Copper	102.6	46.8	47.3	0.8	ND	ND	220	159	86
Copper (SPLP)	0.01	0.03	0.20	NT	NT	NT	NT	NT	NT
Lead	128.7	68.1	48.0	59.6	38.2	39.9	328	372	210
Lead (SPLP)	ND	ND	ND	NT	NT	NT	NT	NT	NT
Zinc	269.9	115.3	74.8	227.6	138.0	140.3	470	463	324
Zinc (SPLP)	ND	0.02	0.03	NT	NT	NT	NT	NT	NT

NT = Not tested; ND = Not detected.

Figure 1. SIMPTM Calibration: Durand Single-Family Residential Site

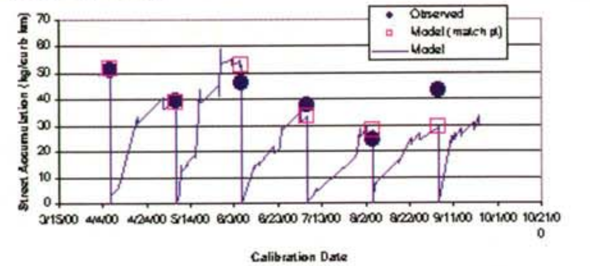
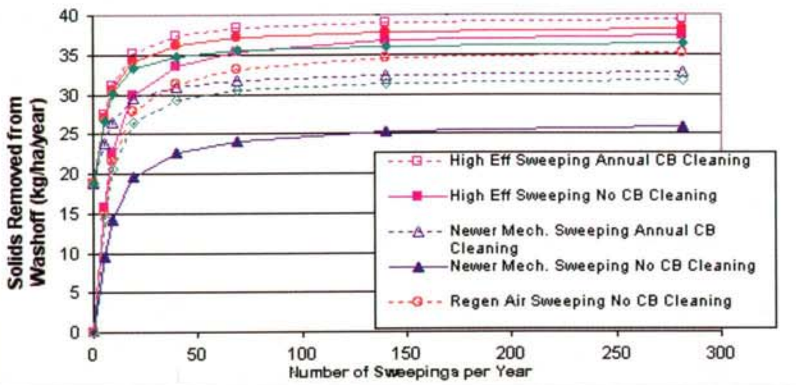


Figure 2. BMP Production Functions: Livonia Single-Family Residential Sites



(a process called armoring, in which larger particles rest on and pin smaller ones). The fraction generally considered available for transport (particles smaller than 250 μm) made up 26% and 36% of the total accumulated sediment in Jackson and Livonia, respectively.

After the physical analyses of the first, third, and fifth set of samples (those collected in both study areas), fractions were recombined into three size groups for chemical analysis by a certified laboratory. Samples smaller than 63 μm were labeled "fine," those between 63 and 250 μm were labeled "medium," and those between 251 and 6370 μm were labeled "coarse." Samples larger than 6370 μm were discarded.

Chemical Analysis

Both project teams analyzed their fine, medium, and coarse samples for total phosphorus, chemical oxygen demand (COD), arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, copper, and zinc (see Table 2, p. 61, and Table 3, p. 61). The Jackson team also analyzed samples for chloride. In addition, the teams analyzed a final set of composite samples for all of these parameters and for leachable metals, using a modified synthetic precipitation leaching procedure (SPLP). The SPLP was selected instead of a toxic characteristic leaching procedure because it provided a more realistic assessment of dissolved pollutant mobility under actual rainfall-to-runoff conditions.

The modified SPLP simulated the sediment leaching process that results from rainfall and runoff conditions in southern Michigan. It involved weighing a sample and adding 20 times the sample's weight in an acidic fluid (pH 4.5; the average pH of the region's rainfall). The mixture was then tumbled for 8 hours (the average duration of the region's rainfall) and then put through a digestion process involving nitric acid.

Load Estimation Procedure

The basic steps in the SIMPTM load estimation procedure, which was developed and refined over the last 10 years, are as follows:

- Select test areas representative of the predominant urban land uses in the study area or watershed of interest.
- Monitor the initial accumulations of sediment on streets and parking areas and within catch basins throughout these test areas.
- Arrange to have the catch basins cleaned after the initial monitoring.
- Periodically monitor over time the sediment accumulations in the test area on streets, parking lots, and catch basins.
- Obtain hourly precipitation readings from a nearby gauge or monitor precipitation at these test areas during the accumulation monitoring period.
- Conduct mechanical analyses (sieve) on the collected sediment samples.
- Conduct chemical analyses on three composted fractions of the sieved sediment samples.
- Calibrate SIMPTM using sediment accumulation observations over the monitoring period.
- Develop an average rainfall year through analysis of rainfall data from a nearby gauge with a long period of record.
- Document existing cleaning practices including unit costs (factor in snow and ice control, if applicable).
- Use SIMPTM to conduct a BMP evaluation for the average rainfall year.
- Use SIMPTM to simulate pollutant washoffs during the average rainfall year.

In regard to TMDL analyses, pollutant washoff loadings can be used directly to establish TMDLs; they can also serve as needed input to in-stream water quality models whose output could establish TMDLs. In the studies mentioned in this article, TMDLs were not developed; instead, the focus was on identifying the costs and pollutant reduction benefits associated with optimal efforts to clean streets and catch basins.

Table 4. Observed Versus Simulated Street Dirt Accumulations

PROJECT: LIVONIA

Land Use/Site Name	Test Area	Sampling Data	Observed Accumulation kg/ha	(lb/acre)	Simulated Accumulation kg/ha	(lb/acre)	Difference %
	1-G	9/10/99	209	(184)	214	(189)	+3
Shopping Center	1-G	11/4/99	151	(133)	179	(158)	+16
Commercial	1-G	1/6/00	874	(771)	-	-	
	1-G	3/24/00	127	(144)	194	(171)	+16
Newburgh	1-P	3/24/00	447	(394)	447	(394)	0
	1-P	5/16/00	192	(169)	200	(176)	+4
	2A-G	9/10/99	210	(185)	210	(185)	0
Recreational Area	2A-G	11/4/99	109	(96)	134	(118)	+18
Parking	2A-G	1/6/00	152	(134)	158	(139)	+4
	2A-G	3/24/00	138	(122)	120	(106)	-15
Fox Creek	2A-P	3/24/00	296	(261)	296	(261)	0
	2A-P	5/16/00	350	(309)	172	(152)	-103
	15-G	9/10/99	152	(134)	152	(134)	0
Single-Family Residential	15-G	11/4/99	26	(23)	107	(94)	+75
	15-G	1/6/00	48	(42)	74	(65)	+35
Munger	15-G	3/24/00	23	(20)	39	(34)	+41
	15-P	3/24/00	32	(28)	42	(37)	+24
	15-G	5/16/00	314	(277)	87	(77)	-259
	15-P	5/16/00	23	(20)	87	(77)	+74
	20-G	9/10/99	40	(35)	40	(35)	0
Single-Family Residential	20-G	11/4/99	44	(39)	51	(45)	+13
	20-G	1/6/00	45	(40)	71	(63)	+36
Riverside	20-G	3/24/00	29	(26)	34	(30)	+13
	20-P	3/24/00	66	(58)	39	(34)	-70
	20-G	5/22/00	126	(111)	99	(87)	-27
	20-P	5/22/00	40	(35)	99	(87)	+59

PROJECT: JACKSON

Land Use/Site Name	Test Area	Sampling Data	Observed Accumulation kg/ha	(lb/acre)	Simulated Accumulation kg/ha	(lb/acre)	Difference %
			4/6/00		51	(180)	51
(182)		+1					
Single-Family Residential	1	5/4/00	39	(140)	37	(132)	-6
		6/8/00	46	(163)	52	(186)	+14
Durand		7/11/00	37	(132)	33	(118)	-11
		8/9/00	24	(85)	28	(100)	+18
		9/6/00	43	(152)	29	(103)	-32
		4/7/00	87	(309)	88	(312)	+1
Single-Family Residential	2	5/4/00	59	(209)	75	(264)	+26
		6/8/00	69	(243)	71	(247)	+2
Jackson		7/11/00	44	(157)	64	(228)	+45
		8/9/00	82	(289)	62	(217)	-25
		9/6/00	69	(243)	64	(227)	-7
		4/7/00	56	(198)	56	(197)	<1
Central Business District	3	5/11/00	28	(98)	41	(144)	+47
		6/8/00	38	(135)	45	(160)	+19
Cortland		7/12/00	32	(113)	33	(117)	+4
		8/10/00	51	(180)	29	(103)	-43
		9/6/00	30	(108)	31	(112)	+4
		4/6/00	109	(385)	109	(386)	<1
Highway	4	5/4/00	102	(359)	77	(272)	-24
		6/6/00	72	(256)	88	(311)	+22
Parnell		7/17/00	52	(186)	68	(242)	+30
		8/8/00	73	(260)	62	(218)	-16
		9/13/00	51	(180)	66	(235)	+31
		4/6/00	187	(660)	188	(663)	<1
Industrial	5	5/4/00	142	(501)	146	(517)	+3
		6/9/00	166	(587)	137	(484)	-18
Carroll		7/11/00	103	(364)	132	(468)	+29
		8/9/00	127	(449)	123	(435)	-3
		9/6/00	92	(324)	135	(478)	+48
		4/6/00	70	(247)	73	(257)	+4
Single-Family Residential	6	5/11/00	27	(97)	61	(215)	+122
		6/8/00	69	(244)	70	(249)	+2
Seymour		7/12/00	53	(188)	53	(189)	<1
		8/9/00	52	(185)	50	(177)	-4

Table 5. Observed Versus Simulated Catch Basin Accumulations

Project	Site name	Monitoring date	No. of catch basins	Observed accumulation Avg. depth of material cm	(ft)	Simulated accumulation Avg. depth of material cm	(ft)
Livonia	Newburgh	5/11/00	7	1.8	(.06)	0.6	(.02)
	Fox Creek	3/24/00	8	1.2	(.04)	1.5	(.05)
	Munger	5/11/00	8	1.5	(.05)	0.6	(.02)
	Riverside	3/24/00	14	0.9	(.03)	0.3	(.01)
Jackson	Durand	9/6/00	1	4.3	(.14)	1.2	(.04)
	Jackson	8/9/00	1	46.3	(1.52)	1.5	(.05)
	Cortland	9/16/00	1	2.4	(.08)	0.6	(.02)
	Parnell	9/13/00	1	61.0	(2.00)	0.9	(.03)
	Carroll	9/6/00	1	31.4	(1.03)	6.4	(.21)
	Seymour	8/9/00	1	1.8	(.06)	0.9	(.03)

Table 6. Optimal Effort Levels of Various BMPs on Single-Family Residential Areas in Livonia, Mich.

BMP description	Optimal level of effort in sweeping frequency	Marginal cost $/kg removed ($/lb removed)	Solids removed from washoff annually kg/ha (lb/acre)	Percent reduction in solids washoff
HS & annual CBC	every 15 days	25.24 (11.36)	39.9 (35.2)	84%
RS & annual CBC	every 15 days	28.98 (13.04)	38.7 (34.1)	81%
HS & no CBC	every 15 days	14.09 (6.34)	33.8 (29.8)	71%
TS & annual CBC	every 30 days	23.53 (10.59)	34.1 (30.1)	72%
RS & no CBC	every 15 days	15.87 (7.14)	31.6 (27.9)	66%
MS & annual CBC	every 30 days	15.38 (6.92)	30.0 (26.5)	63%
TS & no CBC	every 30 days	12.91 (5.81)	23.4 (20.6)	49%
MS & no CBC	every 15 days	18.51 (8.33)	22.2 (19.6)	47%

HS = high-efficiency sweeping; RS = regenerative air sweeping; TS = tandem sweeping; MS = mechanical sweeping; CBC = catch basin cleaning.

Precipitation Data

To calibrate the SIMPTM model properly, hourly precipitation data must be recorded throughout the entire monitoring period at a station close to the test areas. If the data are collected by others, the information should be available within 4 to 6 weeks of its collection. If these conditions cannot be met, the project team will need to install and maintain a precipitation gauge at a location central to the test areas.

Forty-one runoff-producing rainfall events, with a total depth of 557 mm (21.94 in.) occurred during the Jackson project's monitoring period. In Livonia, 52 runoff-producing rainfall events, with a total depth of 418 mm (16.46 in.), occurred during the monitoring period.

SIMPTM Calibration

SIMPTM simulates the accumulation and washoff of sediments and their associated pollutants. It relates sediment washoff to washoff of other pollutants by potency factors assigned to each of the eight sediment-size groups. The factors are generally set based on observed fractions of accumulated sediment or observed sediment and pollutants washed off during sampled events. In these projects, the pollutant washoff simulations were based on the chemical analyses of sediment samples.

To calibrate SIMPTM, the project teams focused on reproducing observed sediment accumulations on paved surfaces and in catch basins for each test area (see Table 4, p. 63, and Figure 1, p. 62). The underlying assumption is that if the model can accurately simulate these accumulations over time, it should provide reasonably accurate estimates of the solids washoff that occurred during the monitoring period.

In the Livonia project, the team's initial monitoring occurred on Sept. 13, 1999, and catch-basin cleaning was first simulated on Oct. 7, 1999. In the Jackson project, the team's initial monitoring occurred on April 7, 2000, and catch-basin cleaning was first simulated on April 10, 2000. Catch-basin accumulations in both projects ranged from empty to 1.08 m (3.55 ft) deep. The teams then compared the simulated accumulations with observed accumulations near the end of the monitoring period at each site (see Table 5, above).

In the Livonia project, where 7 to 14 catch basins were monitored at each test area, SIMPTM provided reasonable estimates of the magnitude of average accumulated sediment in the catch basins over a short period of time. However, because the model generally underestimated these accumulations, any conclusions about catch-basin cleaning's effect on pollution reduction would be conservative.

In the Jackson project, where only one catch basin was monitored at each test area, the model significantly underestimated the amount of sediment accumulating in the catch

Figure 3. BMP Total Cost Curves: Livonia Single-Family Residential Sites

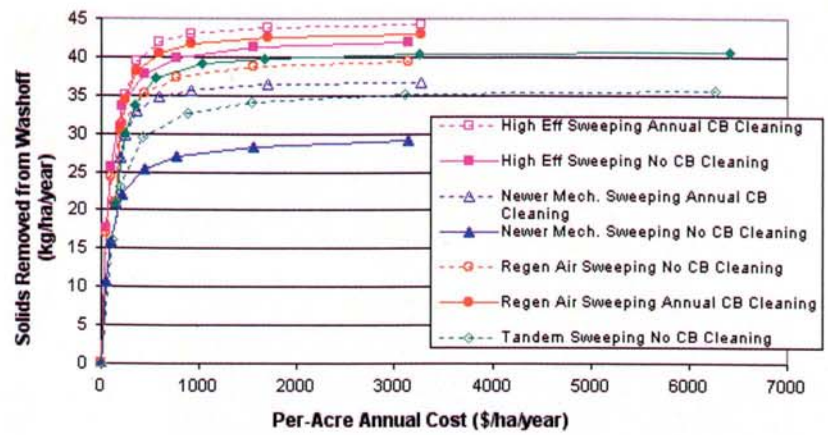
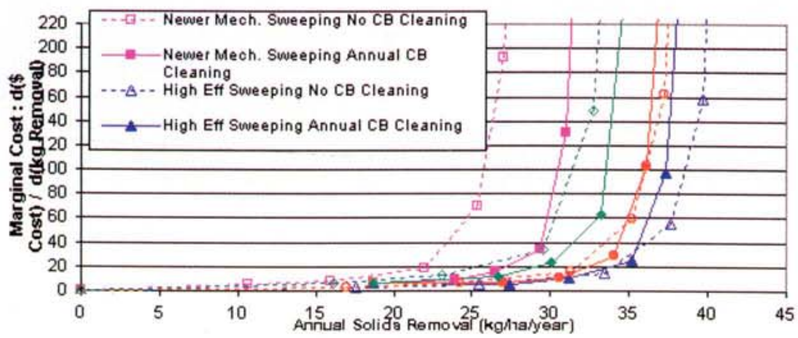


Figure 4. BMP Marginal Cost Curves: Livonia Single-Family Residential Sites



basins over time. However, given the large range of accumulations found in the Livonia test areas during sampling, it is clear that the decision to sample only one catch basin at each Jackson test area was a mistake that should not be repeated.

Also, the depth measurements may have included organic material, which can occupy a considerable amount of volume and is not simulated by the model. It is unclear whether the field monitoring crews were aware of the distinction between sediment and organic material or were simply measuring and reporting the depth of material accumulation.

Developing an Average Rainfall Year

Rather than execute the model for many years of rainfall and summarize extensive results, the project teams analyzed a long precipitation record to create an "average rainfall year" to be used to evaluate various best management practices (BMPs).

To do this, the teams noted all runoff-producing events — at least 1.0 mm (0.04 in.) in 1 hour, 1.8 mm (0.07 in.) in 3 hours, or 2.3 mm (0.09 in.) in 6 hours — in the multi-year precipitation record and summarized each month according to the following parameters:

- number of events,
- total duration of events,
- total depth of events,
- maximum hourly precipitation,
- average intensity, and
- average dry time preceding events.

They then compared all the data for each January in the record and determined which one most closely approximated the long-term mean. Then they did the same for February through December, and combined these chosen months to synthesize a truly average year of rainfall. The synthesized year excluded rain events during winter, when frozen conditions usually existed (Dec. 21 to Feb. 21 in Livonia, and Dec. 21 to March 15 in Jackson).

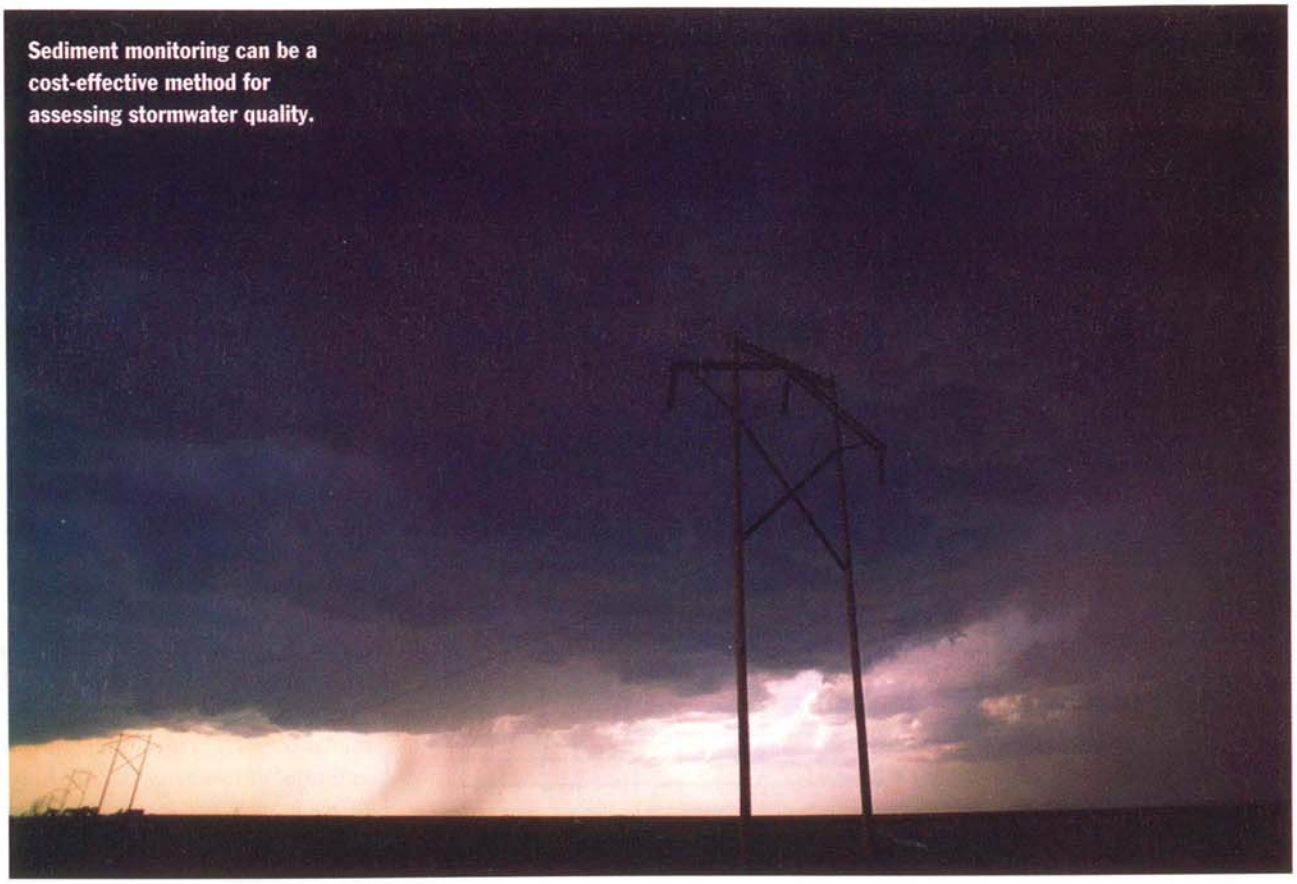
So, Livonia's average rainfall year contained 61 runoff-producing events between Feb. 22 and Dec. 20. The events totaled 630 mm (24.79 in.) of rainfall over 387 hours, yielding an average rainfall intensity of 1.63 mm/hr (0.064 in./hr). The average event was 10.4 mm (0.41 in.) and lasted for about 6.35 hours.

Jackson's average rainfall year contained 63 runoff-producing events between March 16 and Dec. 20. The events totaled 546 mm (21.51 in.) of rainfall over 271 hours, yielding an average intensity of 2.01 mm/hr (0.079 in./hr). The average event was 8.6 mm (0.34 in.) and lasted for about 4.30 hours.

BMP Analysis

The project teams modeled average annual total suspended solids (TSS) loadings or washoffs on a unit acre basis for a large array of BMPs, including catch-basin cleaning, mechanical street sweeping, tandem sweeping (vacuum-assisted followed by mechanical), regenerative air sweeping, and high-efficiency sweeping (see Figure 2, p. 62). [High-efficiency street sweepers use strong vacuums and the mechanical action of uniquely designed main and gutter brooms combined with an air-filtration system that returns only clean air to the atmosphere (they filter particulates to 2.9 µm). These machines sweep dry, and no water is used because they do not emit dust.]

The street-sweeping frequencies (days between sweepings) modeled were 61, 30, 15, 7, 4, 2, and 1. Because sweeping was assumed not to occur in winter, the actual number of sweepings that corresponded to the above frequencies were 5, 9, 19, 40, 69, 140, and 282 times per year, respectively. The frequency of catch-basin cleaning in BMP simulations was assumed to be annual, so the model began the average year



simulation with clean and empty catch basins. The teams also modeled a year without any cleaning in order to calculate how effective each BMP was in removing TSS from washoff (measured by mass per area per year).

Total Cost Curves

The next step was to compare TSS reduction and total cost for each BMP (see Figure 3, p. 65). Using data provided by Livonia, the project team estimated that catch-basin cleaning cost $44.25 per catch basin and street sweeping cost $47.80/km ($76.90/mi) of curb swept. In Jackson, catch-basin cleaning cost $28.75 per catch basin cleaned, and street sweeping cost $87.00/km ($140/mi) of curb swept. These costs include labor, overtime, equipment, and overhead associated with each activity.

Note that for any given BMP, solids removal increases as total costs increase. Early on, any given BMP will remove a good amount of solids inexpensively. As removals increase, however, costs increase more rapidly.

Optimal levels and marginal costs. To find the optimal level for any given BMP, the relationship between solids removal and related costs must be understood. So, the project teams developed marginal cost curves for each BMP (see Figure 4, p. 65). Based on Figure 4, the team concluded that $22/kg ($10/lb) of solids removed from washoff is a reasonable level of effort. This conclusion is somewhat subjective, but it was chosen because it was the point at which the least-effective practice (newer mechanical sweeping with no catch-basin cleaning) was becoming very expensive.

Note that each BMP removes different levels of solids at the $22/kg ($10/lb) limit. BMPs that remove less solids at this limit are less cost-effective than those that remove more solids at this limit (see Table 6, p. 64).

Conclusions

Results show that annual catch-basin cleaning and street sweeping every 15 to 30 days could reduce annual TSS loadings by up to 80%. In southern Michigan's urban areas, the most cost-effective sweeping practice seems to be high-efficiency or regenerative air sweeping.

These projects also show the value of a model based on sediment monitoring. This procedure, which can be implemented for 10% to 20% of the cost of monitoring end-of-pipe stormwater flow and concentrations, offers TMDL analyses that provide reasonably accurate urban stormwater pollutant washoffs, optimal effort levels for street sweeping and catch-basin cleaning practices, and an understanding of the pollutant load reductions associated with various street sweeping and catch-basin cleaning practices. A serious re-examination of the actual stormwater quality benefits associated with these maintenance practices is needed throughout the United States and the world.

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