Title: Storm Water Transport of Particulate Matter From Elevated Urban Transportation Corridors into Waterways of Louisiana – The Role of Partitioning and Implications For Treatment

Project Number:

Start Date: March 2001

End Date: March 2002

Research Category: NPP, TRT, HYDROL, TS

Descriptors: Urban Hydrology, Granulometry Elevated Infrastructure, Storm water, Mitigation, Heavy Metals, Particle Transport, Best Management Practices (BMP)

Lead Institution: Louisiana State University (Civil Engineering, Chemistry Departments)

Investigators: John J. Sansalone, P.E. (LSU), Frank K. Cartledge (LSU),
Marty E. Tittlebaum (University of New Orleans)

Students Supported: Two Master of Science students (Civil and Environmental Engineering)

Problem Statement:

Since passage of the 1972 Clean Water Act, storm water nonpoint pollution has advanced from being a problem that was understood only well enough to realize the difficulties associated with application of conventional unit operation and process design, to now becoming the wastewater of the next several decades and our most important water treatment challenge. From urban interstate highway pavement alone, annual heavy metal, total suspended solids (TSS), chemical oxygen demand (COD) loadings and storm water flows have been shown to equal or exceed annual loadings and flows from untreated domestic wastewater for a given urban area (Sansalone et al., 1998). Storm water runoff, impacted by both urban transportation activities and associated urban transportation infrastructure, transports significant loads of dissolved, colloidal and suspended solids in a complex heterogeneous mixture that includes heavy metals, inorganic and organic compounds. Urban storm water levels of Zn, Cu, Cd, Pb, Cr, and Ni are significantly above ambient background levels, and for many urban and transportation land uses often exceed surface water discharge criteria on an event basis for both dissolved and particulate-bound fractions (Sansalone et al, 1997). Storm water transports a wide gradation of particulate matter ranging in size from smaller than 1-μm to greater than 10,000-μm (Sansalone et al, 1998). From water quality and potential treatment perspectives, entrained or engineered solids having reactive sites and large surface-to-volume ratios are capable of mediating transport of heavy metals.

With very few exceptions, runoff from elevated urban and transportation infrastructure in the United States is discharged directly to the surrounding environment. This is particularly true for challenging conditions typical of Louisiana. In Louisiana transportation infrastructure of urban areas, industrial corridors and inter-urban corridors is commonly elevated, and discharge storm water directly to waterways, estuaries, marshes and coastal areas. In fact, Louisiana has more elevated transportation infrastructure than any other state except California and over 80% of Louisiana's transportation infrastructure is over water. The Causeway and a section of I-10 over Lake Pontchartrain and elevated I-10 over the Atchafalaya Basin are well known examples. Since authorization of the NPDES Phase II Storm Water Final Rule in February of 2000, these discharges to receiving water will first require permitting and eventually control. Since NPDES Storm Water Phase I regulations in the 1980s there has been a proliferation of "best management practices" (BMPs). However, experience has demonstrated a significant gap in knowledge exists between BMP design/analysis and a fundamental understanding of unit operations and processes that can demonstrate treatment viability. Much of this gap in knowledge stems from a lack of fundamental understanding of the complex heterogeneous nature of storm water and the interactions that occur in storm water such as heavy metal partitioning to and from particulate matter. Such knowledge is critical to the success of a new generation of storm water treatment systems that will develop in response to the new February 2000 NPDES Phase II Final Rule. This rule requires characterization and permitting of storm water discharges and development of BMPs to control storm water discharges for communities down to populations of 10,000.

Research Objectives:

The fundamental goals of this research study were fourfold. The first objective was to examine the water quality characteristics and the runoff hydrograph from an elevated stretch of an urban interstate site in Baton Rouge. More specifically, the second objective involved the assessment of the partitioning between the dissolved and particulate phases of the respective constituents as they are flushed directly off the bridge surface, as the relative phase distributions have significant implications with regards to treatment design. The third objective quantified the extent to which a disproportionate delivery or "first-flush" type phenomena propagated throughout the duration of the events characterized, as the terminology of this phenomenon implies that this is an ephemeral occurrence phenomena that occurs only during the preliminary stages of an event. Finally, the fourth objective was to evaluate the correlation between the measured conductivity readings and the concentration of total dissolved solids (TDS).

Methodology

Storm water runoff from the I-10 City Park Lake over-pass was sampled for 9 discrete events throughout the course of this study, from which hydrologic and water quality data were collected. Traffic flow characteristics are primary variables that significantly influence pollutant loadings. Consequently, total vehicular counts were performed for all eastbound lanes from which the runoff being sampled drained.

Discrete fully-labeled 1-liter samples were collected from the time of the start of observable rainfall at the site (defined as time = 0) to the cessation of runoff for each particular event. Samples were collected every 2.0 to 5.0-minutes until peak flow was reached and then every 5.0 to 15.0-minutes thereafter, with increased sample spacing to accommodate longer duration events, while at the same time keeping the sample base manageable.

Flow rate measurements are essential to calculate mass loading contributions and were recorded throughout the duration of the storm, from the time of first runoff until the completion of the particular rainfall runoff event. Volumetric flow rates were taken every 2.0-minutes, until the peak of the storm had been measured and then in 5.0-minute increments thereafter, until the end of the rainfall runoff event.

Stormwater Runoff Sample Analysis

Because many water quality parameters are time dependant, time critical data measurements and laboratory analyses were performed immediately or at most within 12-hours of collection with the samples refrigerated at 5^{o}C for the interim. The following water quality parameters were measured immediately in the field: temperature (^{o}C), pH (s.u.) (APHA Standard Method 4500- B), redox potential (+ mv) (APHA Standard Method 2580-proposed), conductivity (μs/cm) (APHA Standard Methods 2510), dissolved oxygen concentration (mg/L) (APHA Standard Method 4500-O- membrane electrode method)

Upon the determination of the end of the event, all samples were returned to the laboratory for further analysis. These analyses (where appropriate) were performed on both the unfractionated sample and the fractionated dissolved phase. The dissolved fraction is that material that passes through a 0.45-μm GFC membrane filter. The time critical laboratory procedures that were performed were: Total alkalinity (mg/L-$CaCO_3$) (APHA Standard Method

2320 B), Phase fractionation between the dissolved and particulate phases (APHA Standard Method 3030 B)

Samples were also fractionated between the total and dissolved phases immediately upon return to the laboratory, for Chemical Oxygen Demand (COD) analysis on the respective phases. That fraction which passed through the 0.45-μm GFC filter constitutes the dissolved phase COD. The particulate fraction was directly inferred from the product of the result of these analyses.

Stormwater runoff samples were fractionated into total suspended solids (TSS) volatile suspended solids (VSS), total dissolved solids (TDS) and volatile dissolved solids (VDS). TSS, VSS and TDS were determined in accordance with the APHA Standard Methods 2540-D, 2540-E, and 2540-C respectively. The methodology to determine VDS is not officially documented in APHA Standard Methods and was determined by igniting the residue from the TDS analysis (APHA Standard Method 2540-C) in a similar fashion to the determination of VSS in Standard Method 2540-E.

All samples were homogenized immediately prior to analysis and between replicate measurements and then placed on a magnetic stir plate to maintain homogeneity while readings were being taken. All analyses, with exception of suspended solids and total turbidity analyses were performed in replicate. TSS, VSS and turbidity were performed in triplicate.

Principal Findings and Significance

One of the key design constraints when considering treatment alternatives for storm water treatment, is the stochastic nature of rainfall-runoff events. This study has revealed that the hydrologic characteristics for storm events for a particular site are highly variable both between events and within the same event. The frequency of occurrence of storm events is not only controlled by prevalent regional climatic conditions, the occurrence of such events also exhibits significant temporal variation within seasonal variations. These temporal variations manifest themselves in the large variability in previous dry hours recorded. This local temporal variability within regional climatic controls is evidenced by the fact, that even though the site is located in sub-tropical climate, on two occasions, within the study occurred two events with previous dry hours in excess of 700 hours.

These temporal variations in both absolute occurrence of an event and variations in intensity within the same event, have fundamental implications for treatment strategy selection and treatment alternative design. Naturally, the stochastic nature of these events precludes the selection of a treatment strategy that involves biological unit processes. The majority of treatment alternatives are linked to biological processes would fail as the microbial populations would soon die when exposed to the extended periods of non-operation. What is also important in rainfall runoff dynamics is the fluctuations in flow rate that can not only varies by orders of magnitude between events, in response to rainfall intensity, but also that the flow rate can also vary by an order of magnitude within the same event.

Another of the principal variables of rainfall-runoff event hydrology is runoff volume. The volume of rainfall runoff, although essentially linked to rainfall amount, duration and intensity, is also affected by previous dry hours and traffic volume. Traffic flow volume will govern the amount of re-entrainment of the rainfall as vehicular spray and as a consequence has a significant impact on not only time of concentration for the runoff, but also the co-efficient of concentration. Traffic flow prior to an event is also a fundamental contributory factor in pollutant accumulation during the previous dry hours leading up to the event. Mass loading rates are obviously fundamentally controlled by rainfall runoff hydrology dynamics, whereas the relative contributions from the dissolved, particulate and particulate-bound phases is a complex relationship between, metal element solubility, partitioning coefficients, the amount of particulate matter in the runoff and the relative concentrations of organic material within this particulate fraction, the pH, ORP and the total alkalinity of the runoff. This complex relationship is shown by the differing f_d values for the same element between storm events.

The stochastic nature of storm events and the highly variable runoff dictates that the proposed treatment alternative must be able to operate over a wide range of loading rates, withstand extended periods of non-operation, and be unaffected by the high heavy metal concentrations without any compromise in pollutant removal efficiencies. This suggests physico-chemical unit operations and processes capable of removing both heavy metals and suspended solids. The toxicity associated with high heavy metal concentrations and also extended downtime would lead to a rapid failure in the biological-type treatments.

The linear site constraints combined with the issues of accessibility associated with elevated structures over water necessitates the collection of the non-point source pollution before treatment. Because of the inaccessibility of elevated structures over water, a treatment system that is passive in application with minimum operational requirements and maintenance is required.

The majority of conventional technologies applied to the treatment of wastewater, although often applicable to the mitigation of urban storm water runoff are not suitable treatment strategies for elevated highways. More often than not, this preclusion is based on simple space availability. Elevated structures do not have hard shoulders or vegetative strips to the side, which could be utilized for the implementation of various treatment strategies.

Table 1. Hydrological indices of the rainfall-runoff events characterized at the City Park Lake bridge

Rainfall Runoff Event	PDH[1] (hrs)	Rainfall duration (min.)	Runoff duration (min.)	Specific Drainage Area				Entire Bridge		
				IPRT[2] (min.)	t_p[3] (min.)	Q_p[4] (L/min.)	V[5] (L)	Q_{pT}[6] (L/min.)	V_T[7] (L)	vds[8]
18 Mar-2000	70	42.0	45.0	10.0	23.0	226.0	1728.0	2806.9	21461.8	5595
5 Jun-2000	720	66.0	76.0	27.0	10.0	10.0	976.5	124.2	12121.9	6705
9 Jun-2000	110	21.0	25.0	3.0	8.0	40.0	326.6	496.8	4056.4	6728
7 Aug-2000	106	48.0	18.0	42.0	32.0	0.9	9.0	11.4	111.8	4350
10 Aug-2000	70	41.0	37.0	8.0	16.0	240.0	3175.5	2980.8	39439.7	4860
21 Sep-2000	238	234.0	210.0	15.0	30.0	150.0	4795.4	1863.0	59558.9	3943
4 Nov-2000	704	75.0	57.0	23.0	50.0	27.0	826.3	335.3	10262.6	2815
13 Dec-2000	170	83.0	92.0	8.0	35.0	240.0	8142.6	2980.8	101131.1	6033
29 Jan-2001	236	181.0	165.0	25.0	164.0	150.0	3184.2	1863.0	39547.8	4114
All events median	170.0	66.0	57	15.0	30.0	150.0	1728.0	1863.0	21461.8	4860.0
All events mean	269.3	87.9	91.222	17.9	40.9	120.4	2493.3	1495.8	30966.4	6132.6
All events SD	258.7	71.6	72.519	12.4	48.0	102.0	2678.9	1266.3	33272.0	4155.7
All events RPD%	164.6	167.1	168.42	173.3	181.4	198.5	199.6	198.5	199.6	142.5

1) PDH = previous dry hours
2) IPRT = initial pavement residence time (measured from time 0 to first runoff)
3) t_p = time to Qp (measured from start of rainfall)
4) Q_p = peak flow from specific drainage area =532-m^2
5) V = Runoff volume from specific drainage area during event
6) Q_{pT} = peak flow from entire bridge deck = 6607-m^2
7) V_T = Total runoff volume from entire bridge deck during event
8) vds = vehicles during storm (I-10: east-bound)
Average Daily vehicles (I-10: eastbound) = 70,400

Table 2. Event based water quality characteristics of the storm water from City Park Lake

Rainfall Runoff Event	Event mean concentrations (EMC)[1]						
	T (^{o}C)	pH (s.u.)	total alkalinity [mg/L]	Conductivity (μs/cm)	Redox (+mV)	Dissolved Oxygen [mg/L]	Turbidity (NTU)
18 Mar-2000		6.9 (6.4-7.0)	23.10 (18-36.0)		394.7 (386.9-418.1)		50.1 (32.6-263.0)
5 Jun-2000	21.9 (21.5-22.0)	6.7 (6.3-6.9)	107.4 (62.0-182.0)	2314.2 (776.0- 11240.0)	469.0 (439.8-476.1)	0.5 (0.1-1.9)	1883.6 (55.3-1049.5)
9 Jun-2000	25.6 (25.8-25.4)	7.3 (6.8-8.4)	30.2 (22.0-208.0)	145.6 (92.6-1050.5)	398.6 (386.1-476.4)	1.8 (0.1-3.1)	121.9 (52.8-1277.0)
7 Aug-2000	27.9 (29.1-29.7)	6.5 (6.8-7.1)	58.1 (56.5-71.0)	1503.7 (479.0-1777.0)	288.3 (274.0-331.0)	4.2 (4.0-4.9)	12.2 (5.3-36.9)
10 Aug-2000	22.0 (22.0-22.3)	6.6 (6.3-6.8)	12.8 (5.0-65.0)	5889.3 1160.5-10073.4)	473.3 (466.0-487.0)	0.3 (0.1-1.9)	101.3 (38.2-1610.0)
21 Sep-2000	25.9 (25.0-26.5)	7.6 (6.7-7.9)	35.2 (25.0-94.5)	158.0 (85.1-1175.1)	511.1 (493.0-624.0)	4.3 (0.2-6.2)	228.2 (43.0-1143.5)
4 Nov-2000	20.1 (19.8-21.5)	7.0 (6.6-7.1)	40.9 (29.5-136.3)	426.1 (266.1-1704.5)	500.9 (487.0-535.0)	1.4 (1.9-9.1)	434.9 (99.7 6290.0)
13 Dec-2000	20.4 (16.8-21.3)	8.1 (7.0-8.5)	16.9 (11.5-90.5)	83.0 (34.0-1180.0)	374.8 (34.0-1180.0)	6.9 (6.0-8.2)	136.3 (55.4-1113.8)
29 Jan-2001	19.3 (17.8-22.7)	8.0 (7.4-8.3)	26.2 (18.6-86.5)	154.3 (46.0-1401.0)	403.8 (387.0-458.0)	7.0 (4.9-7.6)	408.5 (114.3-2221.8)
All events median	22.0	7.0	30.2	292.1	436.4	3.0	136.3
All events mean	22.9	7.2	39.0	1334.3	427.5	3.3	375.2
All events SD	3.2	0.6	29.0	2011.3	75.4	2.7	584.7
All events RPD%	36.4	21.9	157.4	194.4	55.7	183.6	197.4

1) maximum and minimum values in parenthesis

Table 3. Water quality summary data for the rainfall-runoff events characterized

Rainfall Runoff Event	Event Mean Concentrations (EMCs)[1]					
	TSS [mg/L]	VSS [mg/L]	TDS [mg/L]	VDS [mg/L]	COD_p [mg/L]	COD_d [mg/L]
18-Mar-2000	138.0 (57.0-1444.0)	32.5 (16.7-626.0)			142.0 (86.0-7449.0)	57.1 (29.1-419.6)
5 Jun-2000	560.5 (89.3-1302.7)	214.5 (44.7-404.7)	2241.3 (630.4-7204.3)	351.6 (467.0-6470)	585.0 (169.4-887.0)	854.5 (224.4-2524.9)
9 Jun-2000	206.1 (67.7-1809.3)	62.2 (22.3-634.7)	106.0 (67.2-803.1)	49.5 (37.0-648.4)	248.1 (8.1-540.2)	45.9 (14.0-418.9)
7 Aug-2000	32.3 (18.0-703.0)	20.6 (11.0-38.3)	1206.1 (1095.3-1482.4)	430.1 (386.1-512.1)	54.1 (13.1-87.9)	429.6 (289.0-635.0)
10 Aug-2000	225.0 (40.1-1269.3)	99.9 (21.3-213.0)	103.0 (32.3-983.3)	88.0 (30.3-925.9)	71.7 (32.54-804.9)	55.9 (19.5-293.6)
21 Sep-2000	159.7 (50.0-1027.0)	47.8 (26.0-495.0)	154.6 (85.0-1159.3)	75.5 (13.1-916.9)	94.1 (40.0-491.0)	55.3 (16.1-390.0)
4 Nov-2000	442.4 (58.3-8734.7)	148.2 (28-7-2416.0)	274.4 (152.5-882.3)		343.2 (58.4-7185.4)	162.0 (80.5-568.2)
13 Dec-2000	334.4 (40.0-1910.0)	53.0 (9. 0-531.3)	274.4 (55.4-1113.8)		343.2 (10.9-901.4)	162.0 (28.7-379.1)
29 Jan-2001	518.6 (86.7-1837.3)	82.5 (20.7-402.7)	117.8 (38.4-477.5)		151.7 (25.2-839.8)	60.7 (30.5-390.5)
All events median	225.0	62.2	214.5	88.0	151.7	60.7
All events mean	271.9	78.6	515.0	187.3	211.0	186.5
All events SD	159.0	49.2	664.5	167.0	141.4	212.8
All events RPD%	176.5	154.5	179.3	158.7	157.2	173.6