

ANALYSIS OF THE FIRST-FLUSH PHENOMENON AND POLLUTANT RELATIONSHIPS WITHIN STORM WATER RUNOFF FROM TWO SMALL URBAN DRAINAGE AREAS



Sponsored and Funded By:



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First-Flush - An Urban Myth?

STUDY DESCRIPTION

To evaluate the still controversial first-flush (FF) phenomenon (the assumption that pollutant loads are fractionally higher in the initial portion of runoff) on two small adjacent watersheds, 36 storm events were sampled using flow-paced sampling. FF occurrences were calculated using 3 published methods and multiple definitions. Statistical analyses were conducted to determine whether watershed land use affected FF strength and frequency, and which rainfall characteristics influence FF strength.

Drainage Areas

- Storm Water Outfall Channel 3 (Site = SOC 3)
 - > 4.8 Acre Watershed
 - > 68% Impervious Roads
 - > Curve Number = 86
 - > $T_c < 5$ Min.
- Storm Water Outfall Channel 4 (Site = SOC 4)
 - > 5.6 Acre Watershed
 - > 87% Woodland
 - > Curve Number = 69
 - > $T_c < 5$ Min.

Aerial Photo of Drainage Areas



Pollutants Analyzed

- TSS
- Ortho-phosphate
- Ammonia
- Nitrate/Nitrite
- Total Kjeldahl Nitrogen
- Total Phosphorus
- Chromium
- Copper
- Titanium
- Zinc
- Vanadium
- Arsenic
- Nickel
- Lead

First-Flush Evaluation Basis

- Normalized Cumulative Runoff Volume: V'
- Normalized Cumulative Pollutant Load: L'
- Normalized Cumulative Event Time: T'

- Allows for FF comparisons between different size storm/runoff events

FIRST-FLUSH ANALYSIS METHODS

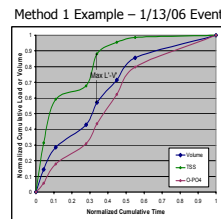
Method 1 - L' & V' vs. T'

FF Definition - Volume up to maximum positive divergence between $L'(t)$ and $V'(t)$

- FF occurrence if $L'(t) > V'(t)$
- Strong FF effect when large divergence value and small V' value

Limitation

- Does not specify V' value of maximum divergence



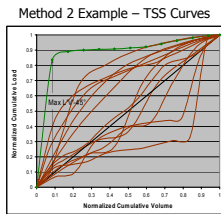
Method 2 - L' vs. V'

FF Definition - Events with 0.2 or greater divergence between $L'V'$ curve and 45° bisector line

- 45° bisector line represents uniform pollutant loading
- Provides quantifiable criteria for FF occurrence

Limitation

- Does not limit FF occurrence to low V' values



Method 3 - Power Function b Coefficient

$$L' = V'^b \gg \text{Log transform} \gg \ln L' = b \ln V'$$

$$b = \text{slope} \quad b = 1 \quad \text{Uniform Loading}$$

FF Definition - $b < 1$ First-Flush Effect

$b > 1$ Dilution Effect

Conventional FF Definitions

20/40 FF - 40% of the pollutant load transported in first 20% of runoff volume.

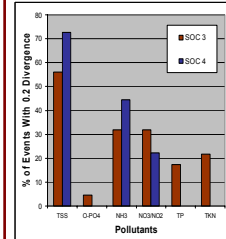
20/80 FF - 80% of the pollutant load transported in the first 20% of the runoff volume.

30/80 FF - 80% of the pollutant load transported in the first 30% of the runoff volume.

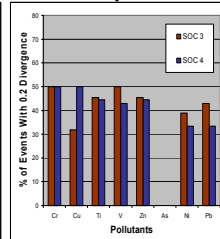
FIRST-FLUSH RESULTS

Method 2: $L'V'$ / 45° Divergence Frequencies

TSS & Nutrients

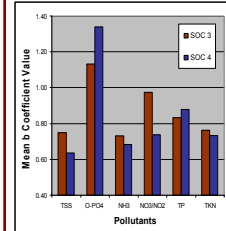


Heavy Metals

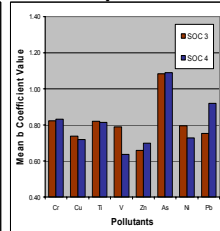


Method 3: FF b Coefficient

TSS & Nutrients



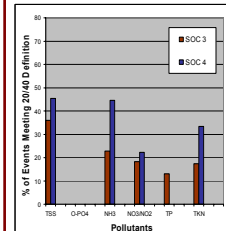
Heavy Metals



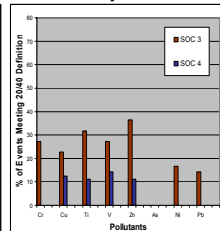
Note: Higher b value indicates weaker first-flush effect ($b < 1$ = first-flush)

20/40 Definition

TSS & Nutrients



Heavy Metals



First-Flush Frequency Ranking

Often Rare

Method 2 : TSS, Cr, Ti, V, Zn, Pb, Ni, Cu, NH₃, NO₃/NO₂, TKN, TP, O-PO₄, As

20/40 FF : TSS, Zn, NH₃, Ti, V, TKN, Cr, Cu, NO₃/NO₂, Ni, Pb, TP, O-PO₄, As

First-Flush Strength Ranking

Strong Weak

Method 3 : Zn, TSS, NH₃, Cu, TKN, Pb, Ni, V, Ti, Cr, TP, NO₃/NO₂, As, O-PO₄

Effect of Rainfall Characteristics on FF

Statistical Method: Simple linear regression

Y: b coefficient X's: rainfall characteristics

Rainfall Characteristics Analyzed

- Rainfall Depth (P)
- Max. Rainfall Intensity
- Antecedent Dry Weather Period
- Peak Flow Rate
- Runoff Volume (V)
- Event Mean Conc.

Significant Correlations with FF Strength (b)

	SOC 3	TSS	Metals	O-PO ₄	SOC 4
Rainfall		↓	↓	↑	No Correlations
Volume		↓	↓	↑	No Correlations

First-Flush Strength Land Use Comparison

Statistical Method: ANCOVA

Y: b coefficient X's: P + Site, V + Site

Results showed that the effect of the site variable had no significant influence on the FF strength (b) after the influence of rainfall depth or runoff volume was accounted for.

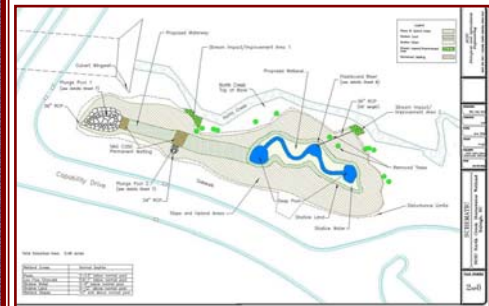
FIRST-FLUSH DISCUSSION

- No statistical difference in FF strength between land uses
- 20/80 and 30/80 FF occurrences very rare, but common for 20/40 rule and more common for the alternative FF methods
- On the highly impervious watershed, rainfall and runoff volume inversely influence FF strength
- O-PO₄ very rarely exhibited FF behavior in impervious or forested drainage areas

FIRST-FLUSH DESIGN SOLUTION

Storm Water Wetland & Plunge Pool System

- Constructed December 2006
- Challenges: Limited land area, steep gradient between storm water culverts and stream
- Designed to store and treat approximately 0.3 inches of runoff from SOC 3 and SOC 4 drainage areas
- Flash-board riser outlet structure located to short-circuit flows after initial "dirty" first-flush water is stored in extended detention



Post Construction



First Rain Event



First Rain Event



Future Work

- Planting of wetland plants (March)
- Monitoring for pollutant load removal efficiencies and system behavior