Modeling Particulate Wash-Off on Rough, Impervious Surface: Field Experiments

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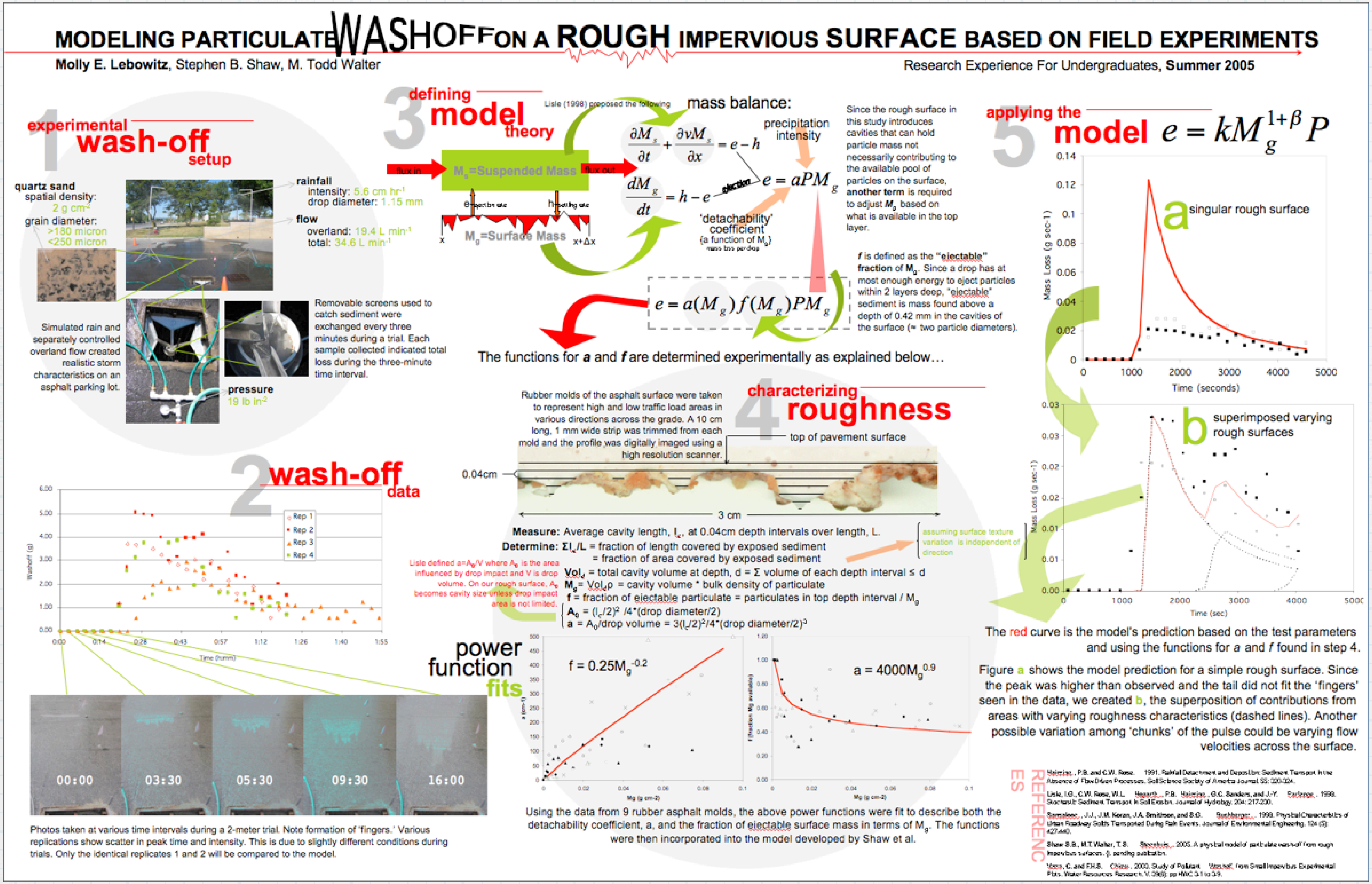
Molly Lebowitz
Cornell University

Note: Press 'skip' on remote to advance slides.

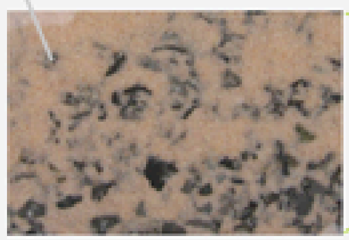

MODELING PARTICULATE WASHOFF ON A ROUGH IMPERVIOUS SURFACE BASED ON FIELD EXPERIMENTS
1 wash-off
2 wash-off
3 model
4 roughness
5 model
a
b
Thank you.

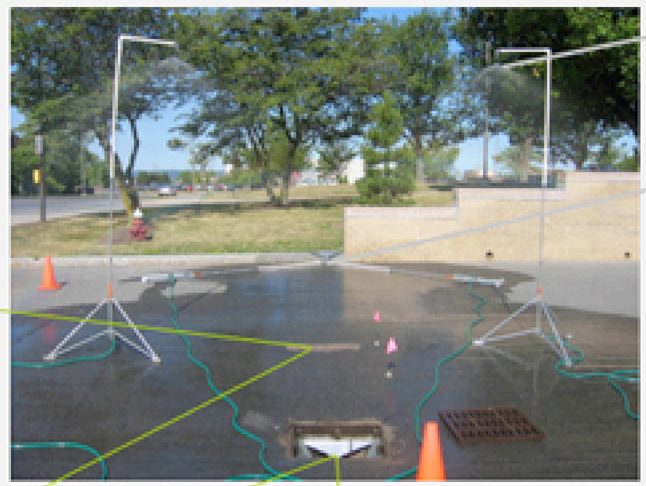


(Close-ups follow.)

1 experimental wash-off setup

quartz sand
spatial density: 2 g cm^{-2}
grain diameter: >180 micron <250 micron

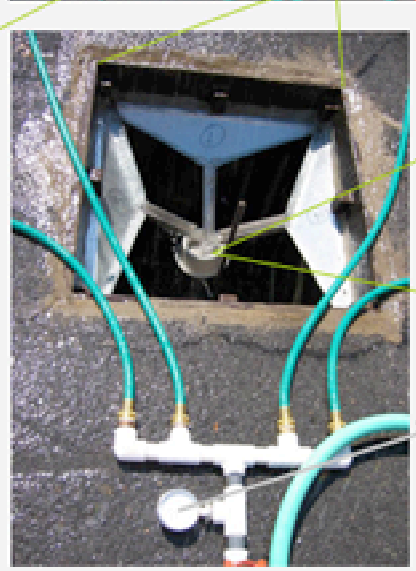


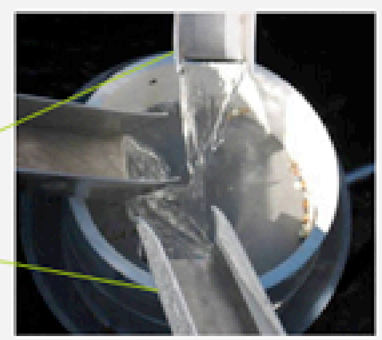


rainfall
intensity: 5.6 cm hr^{-1}
drop diameter: 1.15 mm

flow
overland: 19.4 L min^{-1}
total: 34.6 L min^{-1}

Simulated rain and separately controlled overland flow created realistic storm characteristics on an asphalt parking lot.

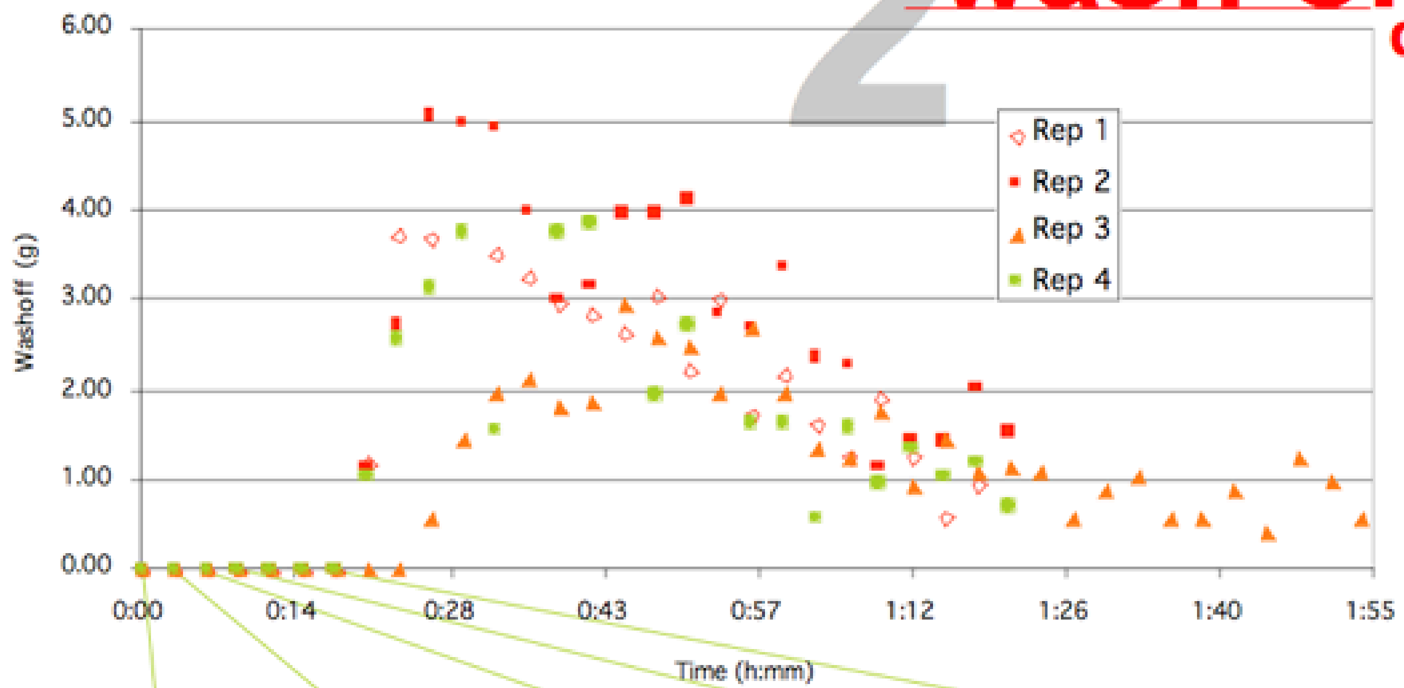


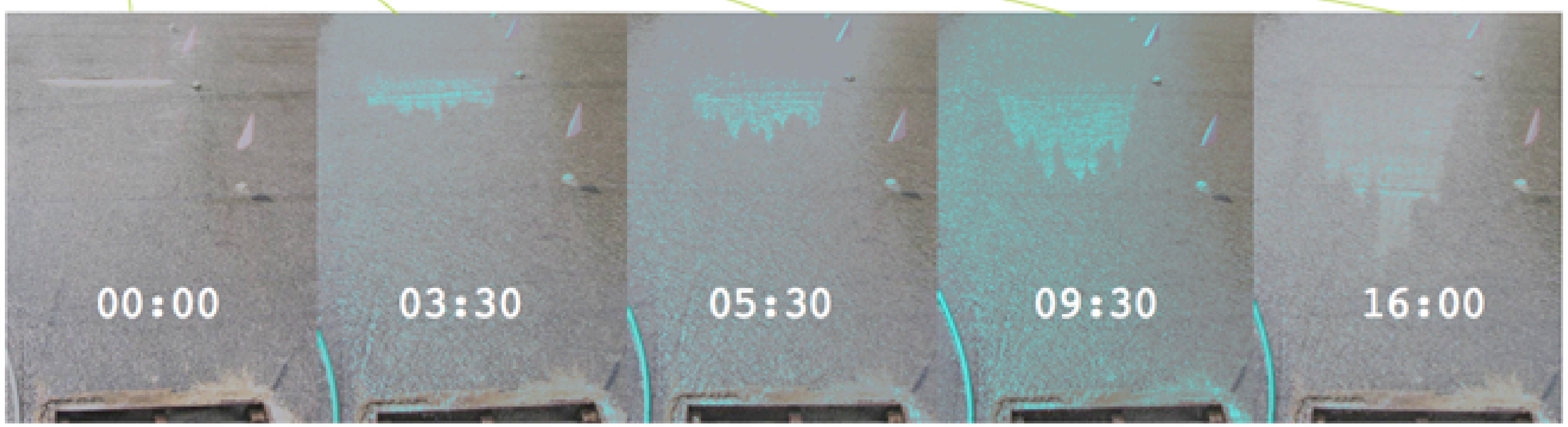


Removable screens used to catch sediment were exchanged every three minutes during a trial. Each sample collected indicated total loss during the three-minute time interval.

pressure
19 lb in^{-2}

2 wash-off data

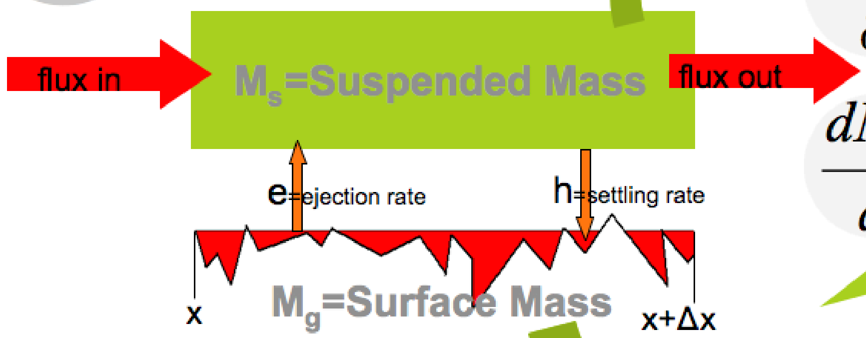




Photos taken at various time intervals during a 2-meter trial. Note formation of 'fingers.' Various replications show scatter in peak time and intensity. This is due to slightly different conditions during trials. Only the identical replicates 1 and 2 will be compared to the model.

3 defining model theory

Lisle (1998) proposed the following



mass balance:

$$\frac{\partial M_s}{\partial t} + \frac{\partial v M_s}{\partial x} = e - h$$

$$\frac{dM_g}{dt} = h - e$$

ejection

precipitation intensity

$$e = aPM_g$$

'detachability' coefficient
{a function of M_g}
mass loss per drop

Since the rough surface in this study introduces cavities that can hold particle mass not necessarily contributing to the available pool of particles on the surface, **another term** is required to adjust $\boldsymbol{M_g}$ based on what is available in the top layer.

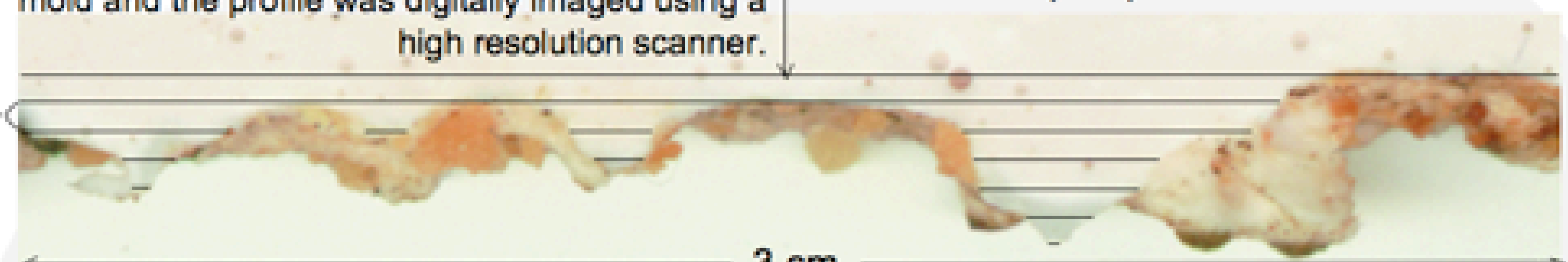
$$e = a(M_g)f(M_g)PM_g$$

f is defined as the **"ejectable" fraction of $\mathbf{M_g}$**. Since a drop has at most enough energy to eject particles within 2 layers deep, "ejectable" sediment is mass found above a depth of 0.42 mm in the cavities of the surface (≈ two particle diameters).

The functions for ***a*** and ***f*** are determined experimentally as explained below…

4 characterizing roughness

Rubber molds of the asphalt surface were taken to represent high and low traffic load areas in various directions across the grade. A 10 cm long, 1 mm wide strip was trimmed from each mold and the profile was digitally imaged using a high resolution scanner.



Measure: Average cavity length, l_c, at 0.04cm depth intervals over length, L.

Determine: $\Sigma l_c/L$ = fraction of length covered by exposed sediment
= fraction of area covered by exposed sediment

assuming surface texture variation is independent of direction

Vol_d = total cavity volume at depth, d = Σ volume of each depth interval ≤ d

$M_g = Vol_d \rho$ = cavity volume * bulk density of particulate

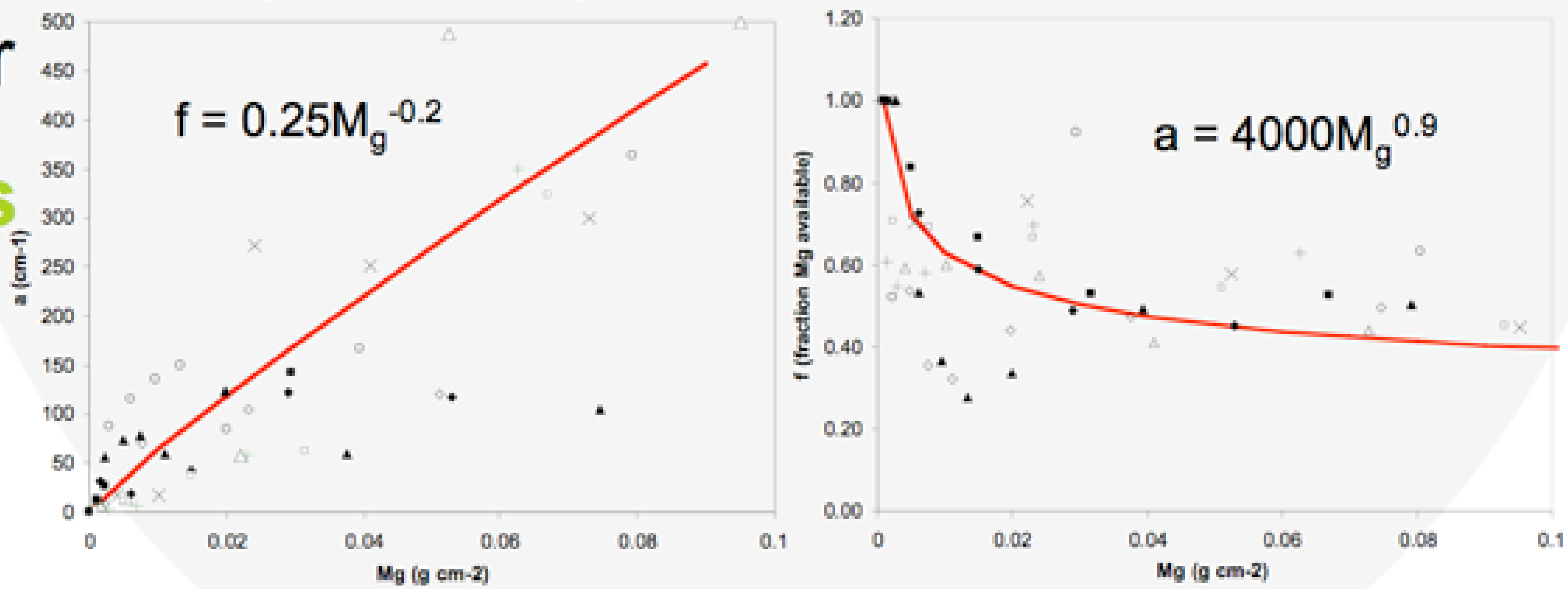
f = fraction of ejectable particulate = particulates in top depth interval / M_g

$A_0 = (l_c/2)^2 /4*(\text{drop diameter}/2)$

a = A_0/drop volume = $3(l_c/2)^2/4*(\text{drop diameter}/2)^3$

Lisle defined $a=A_0/V$ where A_0 is the area influenced by drop impact and V is drop volume. On our rough surface, A_0 becomes cavity size unless drop impact area is not limited.

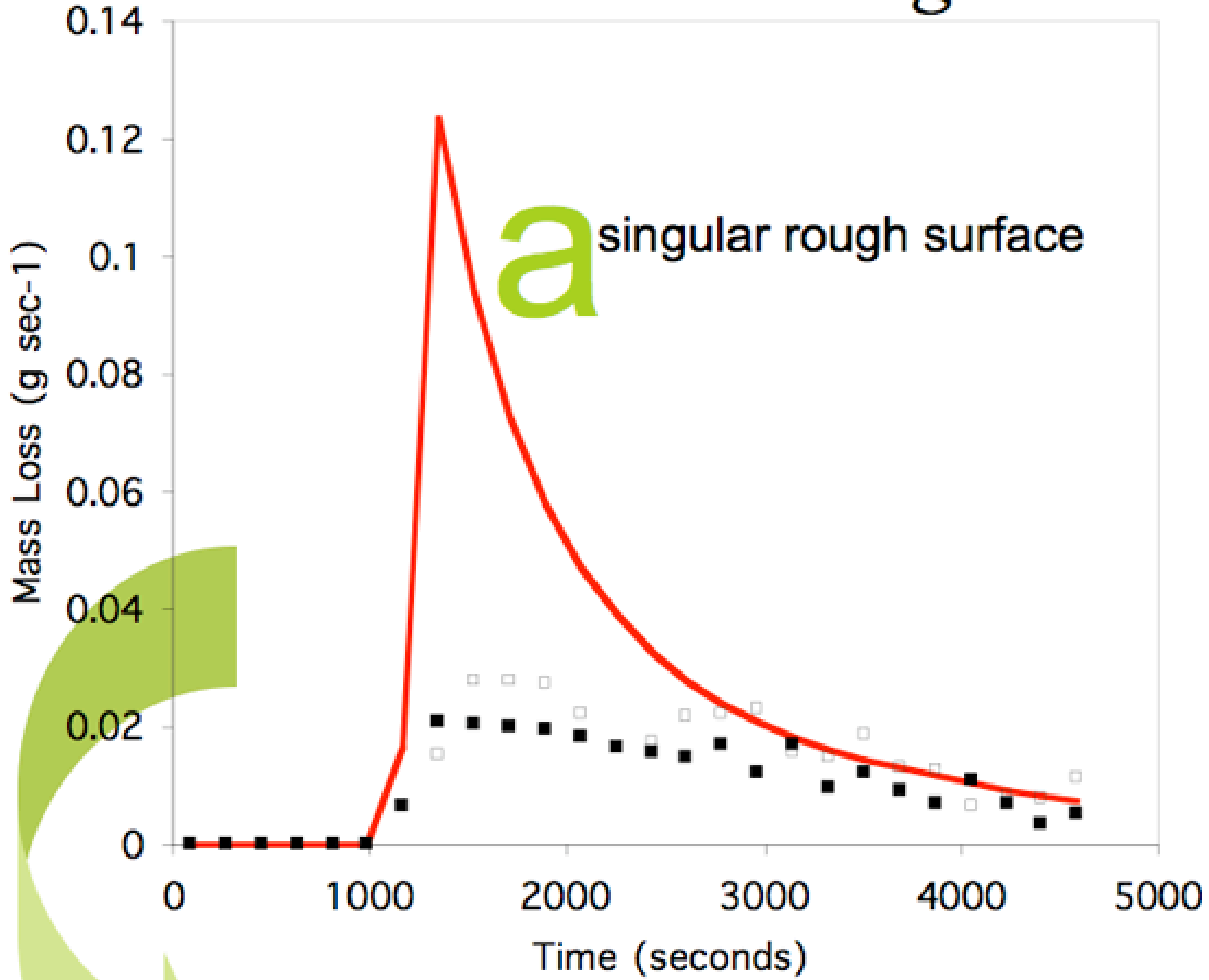
power function fits

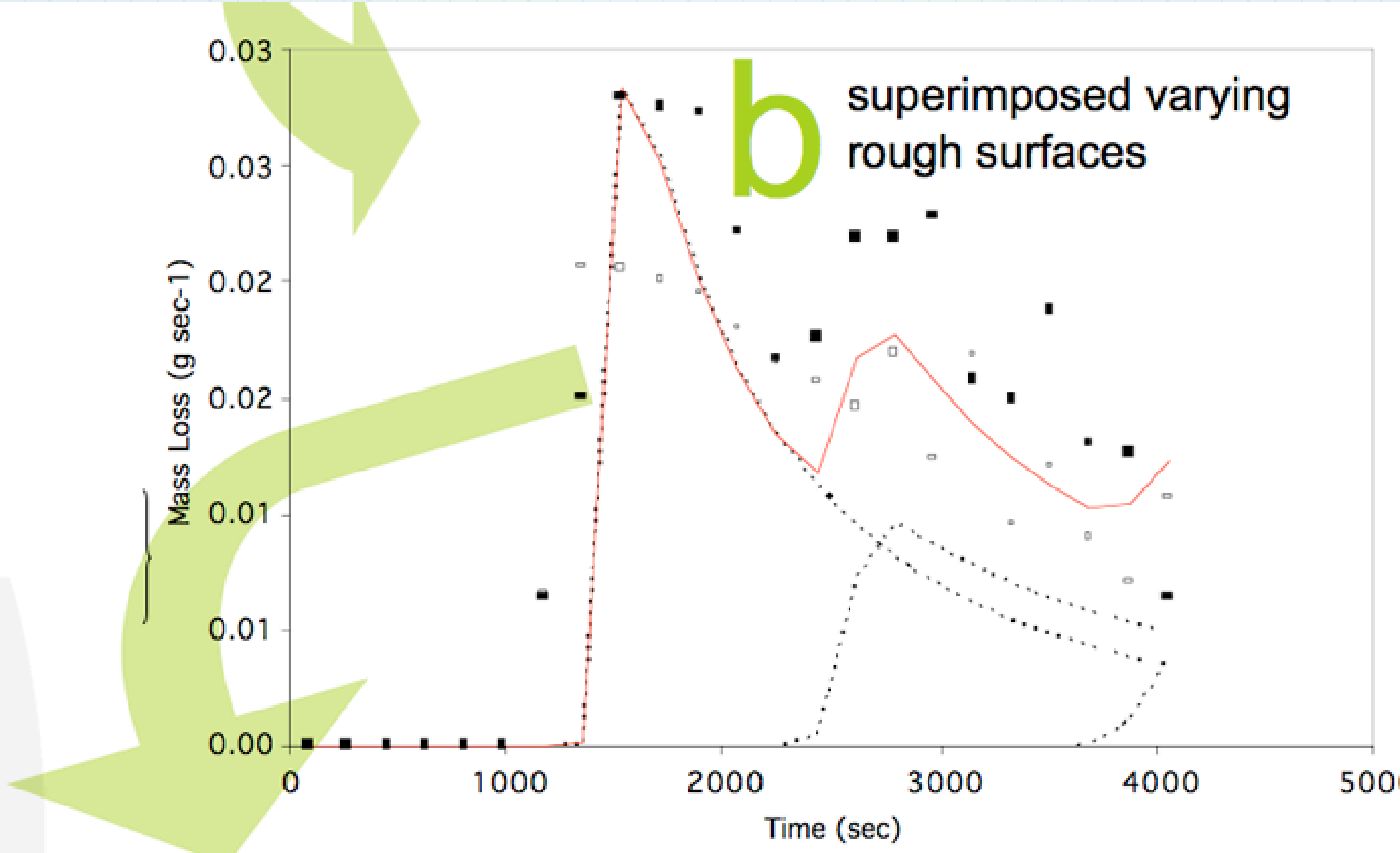


Using the data from 9 rubber asphalt molds, the above power functions were fit to describe both the detachability coefficient, a, and the fraction of ejectable surface mass in terms of M_g. The functions were then incorporated into the model developed by Shaw et al.

5 applying the model

$$e = kM_g^{1+\beta}P$$





The red curve is the model's prediction based on the test parameters and using the functions for *a* and *f* found in step 4.

Figure a shows the model prediction for a simple rough surface. Since the peak was higher than observed and the tail did not fit the 'fingers' seen in the data, we created b, the superposition of contributions from areas with varying roughness characteristics (dashed lines). Another possible variation among 'chunks' of the pulse could be varying flow velocities across the surface.

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