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USING HIGH-RESOLUTION BEDLOAD TRANSPORT TRACER MEASUREMENTS TO INVESTIGATE THE CHARACTERISTICS OF BEDLOAD TRANSPORT OVER A LARGE URBAN FLOOD EVENT

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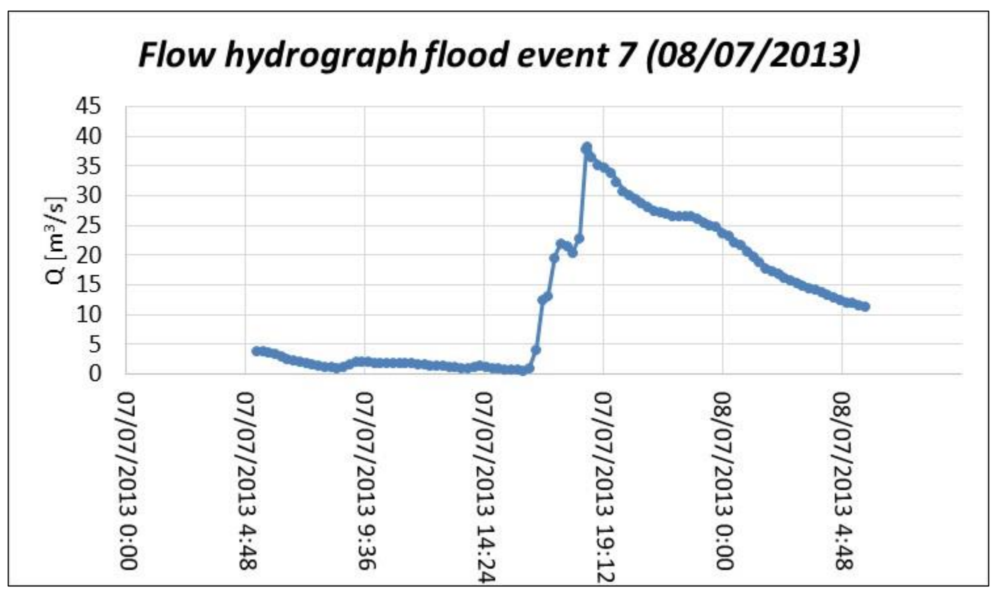
Foreward –The role of sediment transport in river dynamics is essential to evaluating the impacts of large magnitude events [1]. A long-term analysis of a river's dynamics, is required to reasonably assess the quantity of sediment mobilized over the entire flow regime. However, there is a dearth of in-situ sediment transport data available for rivers around the world with even fewer studies obtaining observations during large magnitude events to authenticate the accuracy of event-based transport simulations [2]. The objective is to develop representative sediment transport models of Mimico Creek river reach (Southern Ontario, Canada), that has undergone intensive event-based sediment transport sampling and inter-event bed material particle tracking over a three-year period [3]. A HEC-RAS model was developed of the study reach and calibrated to a series of discharge events where in-situ bedload sampling occurred. Both step-wise discharge and unsteady flow simulations were evaluated to compare sediment transport rates for a range of transport models which included the Meyer-Peter Müller [4] and the Wilcock-Crowe [5]. Calibration curves were developed to estimate sediment discharge in Mimico Creek. The results of the calibrated model were used to calculate the mean travel distance of bed material using the expression for the volumetric rate of bed material transport. Results from the modelling exercise found mean travel distances were similar and in some cases larger than those observed from field measurements, considering both mobile and immobile particles.

Study site – The study focuses on a 2.1 km reach of Mimico Creek (66.3 km²) in southern Ontario, Canada. The majority of the watershed is urbanized with remaining areas zoned as industrial or transportation (airport). Immediately upstream of the study reach, the channel flows within a concrete trapezoidal channel (0.5 km) before transitioning into a gravel-bed channel at the beginning of the study reach. Complete bed material routing is observed throughout the concrete channel section.

July 8th, 2013: a precipitation event occurred generating a flood exceeding the 100-year return period [6]. Pre and post erosion surveys along the 2.1 km reach combined with in-situ and inter-event sediment transport studies and a proximal hydrometric monitoring station afforded a unique opportunity to evaluate the performance of various sediment transport models applicable to gravel-bed rivers for flashy high magnitude events.



Sediment transport measurement and sediment transport modelling and mean bed material travel distance:

- Bedload sampling was conducted during competent floods using the modified single width increment method with 0.076m Helley-Smith samplers between 2012 and 2013 [3].
- Sampling of the coarse particle transport were conducted using tracer particles embedded with RFID (radio-frequency identification) tags between 2011 and 2013 [3].

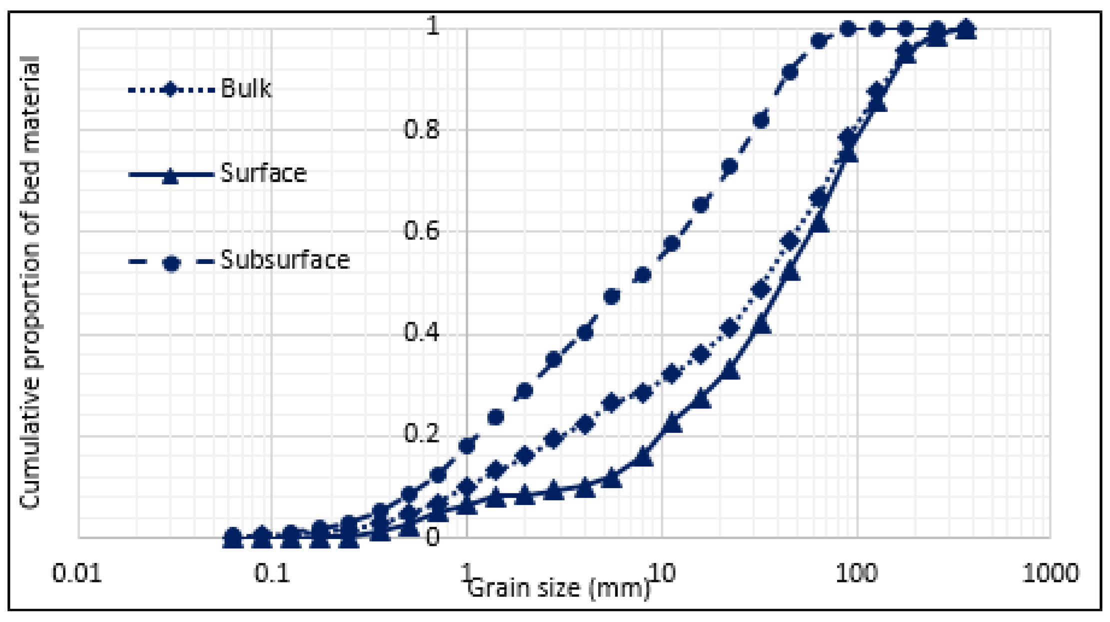
Wilcock-Crowe transport model [5]: $W_i^* = [(s-1)g \cdot q_{bi}]/(F_i \cdot u_o^3)$

Meyer-Peter Müller transport model [4]:

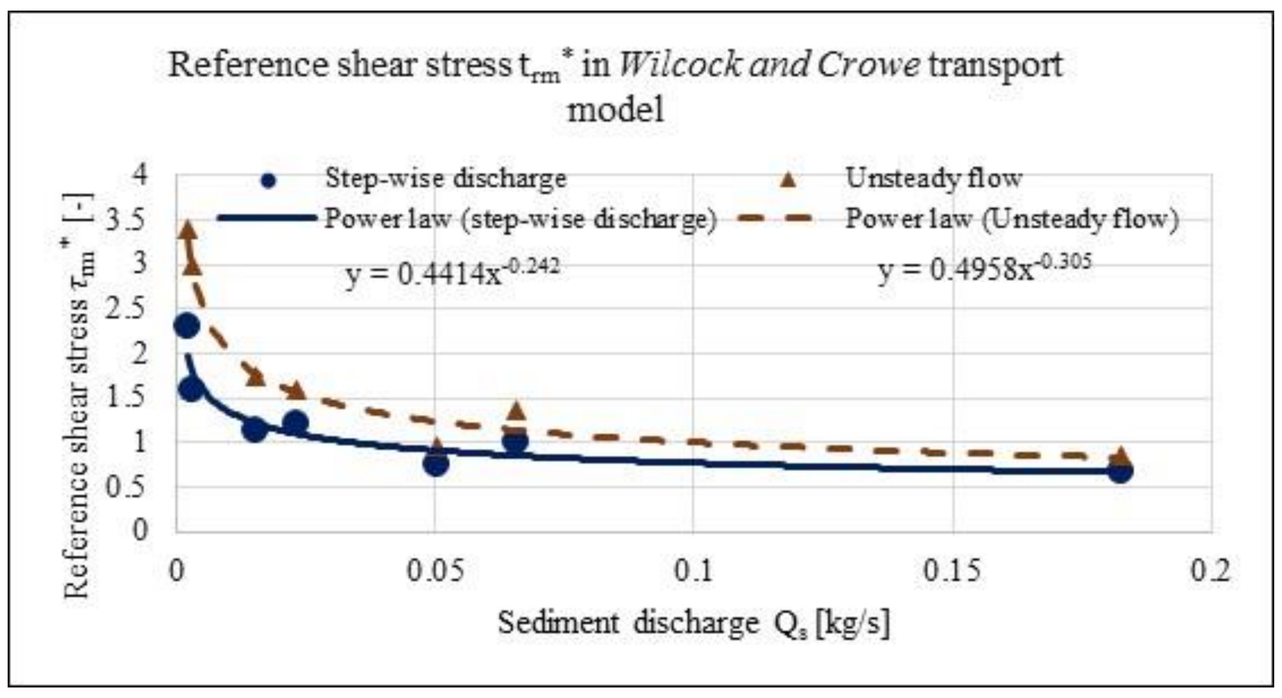
$$\left(\frac{k_r}{k_r'}\right)^{\frac{3}{2}} \gamma \cdot R \cdot S = 0.047(\gamma_s - \gamma) d_m + 0.25 \left(\frac{\gamma}{g}\right)^{\frac{1}{3}} \left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}} g_s^{\frac{2}{3}}$$

Mean bed material travel distances [7, 8]:

$$Q_b = V_b \cdot D_s \cdot W_s(1-P) \qquad \text{where} \qquad V_b = L/\Delta t$$



Representative grain size distribution from the bed material surface and subsurface sampling



Calibration curve for the Wilcock and Crowe transport model

Calibration procedures:

- A calibration curve was developed using the Wilcock-Crowe transport model (considering both step-wise discharge and unsteady flow simulations).
- The calibration parameter (τ_m^*) in the HEC-RAS model was modified to achieve, for each discrete flood event, comparable results between field observed and predicted transport rates.
- The Wilcock-Crowe model was noted to more accurately portray the bulk in-situ sediment transport rates of field observations over the Meyer-Peter Müller equation.
- Using the Meyer-Peter Müller equation, the calibration parameter critical shear stress (τ_C^*) would had to have be set to values beyond the valid parameter range ($50 \le \tau_C^* \le 570$) [9].

Flood Event	Date	Q_{peak} (m³/s)	Q_{b_field} (tonnes/day)	Q_{b_model} (step-wise discharge) (ton/day)	Q_{b_model} (unsteady flow) (ton/day)
1	10/08/2012	15.6	4.35	4.66	4.33
2	04/09/2012	42.3	5.68	5.25	5.73
3	11/03/2013	15.7	0.23	0.31	0.25
4	09/04/2013	16.8	0.17	0.18	0.19
5	12/04/2013	21.4	1.3	1.33	1.28
6	29/05/2013	36.5	1.99	2.02	2.03
7	08/07/2013	38.7	15.79	15.9	15.80

Comparison between sediment discharge measured in the field (Q_{b_field}) and calibrated modelling results (Q_{b_model}) using the Wilcock and Crowe equation.

Estimation of mean travel distance of bed material:

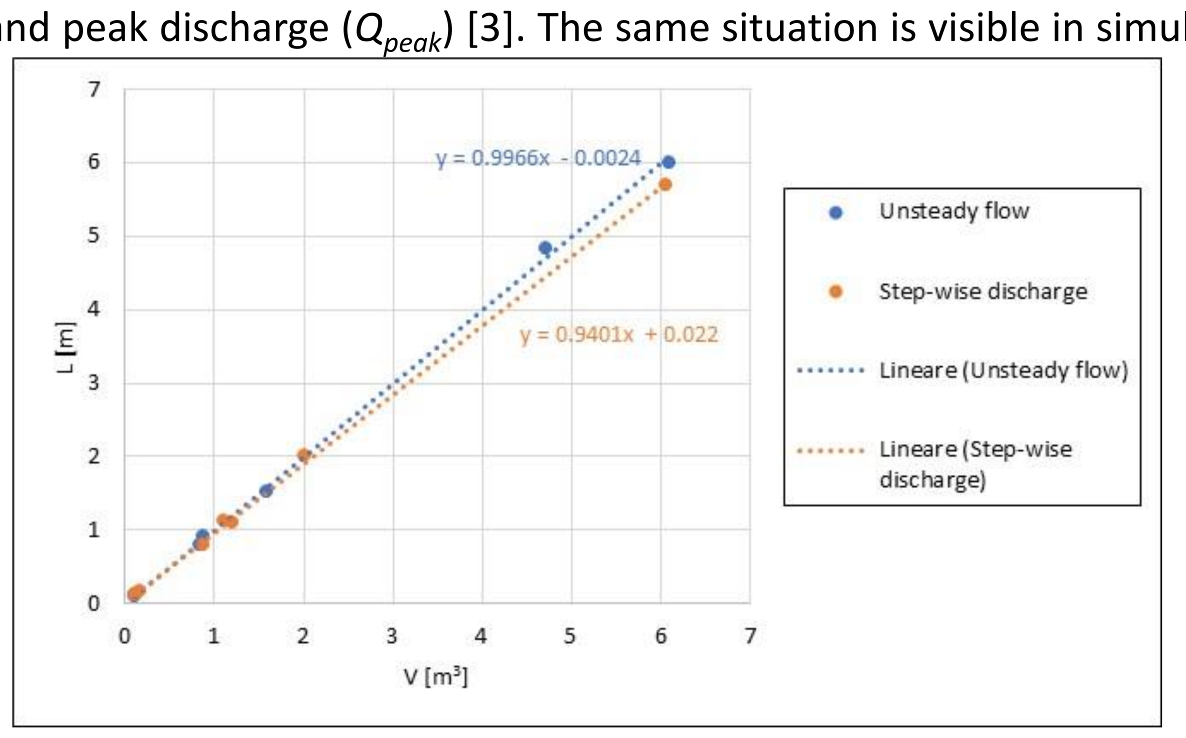
- The results of the calibrated HEC-RAS model were used to estimate the mean travel distance *L* of bed material. L_{m_1} is the mean tracer survey transport distance of event-based particles (including immobile particles), L_{m_2} is the mean tracer survey transport distance of event-based particles (considering only mobile particles).
- *L* varied widely compared to calculated mean field distances. For the 2nd flood event, the simulated (step-wise discharge) *L* is similar to L_{m_1}.
- No relationships were found between L_{m_1} (and L_{m_2}) and peak discharge (Q_{peak}) [3]. The same situation is visible in simulation results, where there is not a monotone function relating Q_{peak} and *L*.

Field Observations [10]				*Simulation Results (step-wise discharge)*		*Simulation Results (unsteady flow)*	
Flood Event	Q_{peak} (m³/s)	L_{m_1} (m)	L_{m_2} (m)	Q_b (m³/s)	*L* (m)	Q_b (m³/s)	*L* (m)
1	15.6	0.4	9.8	$1.3\ 10^{-5}$	1.12	$1.0\ 10^{-5}$	0.92
2	42.3	1.4	8.5	$2.7\ 10^{-5}$	2.00	$6.2\ 10^{-5}$	4.82
3	15.7			$1.8\ 10^{-6}$	0.16	$1.2\ 10^{-6}$	0.11
4	16.8			$1.4\ 10^{-6}$	0.12	$1.4\ 10^{-6}$	0.12
5	21.4			$9.9\ 10^{-6}$	0.80	$9.4\ 10^{-6}$	0.80
6	36.5	3.5	14.4	$1.4\ 10^{-5}$	1.10	$1.8\ 10^{-5}$	1.51
7	38.7			$6.9\ 10^{-5}$	5.70	$6.9\ 10^{-5}$	6.00

Simulation results using Wilcock and Crowe equation for Q_b

	Simulations Results (step-wise discharge)			*Simulation Results (unsteady flow)*		
Flood Event	Q_b (m³/s)	Δt (s)	*V* (m³)	Q_b (m³/s)	Δt (s)	*V* (m³)
1	$1.3\ 10^{-5}$	84600	**1.10**	$1.0\ 10^{-5}$	84600	**0.87**
2	$2.7\ 10^{-5}$	75600	**2.01**	$6.2\ 10^{-5}$	75600	**4.71**
3	$1.8\ 10^{-6}$	89100	**0.16**	$1.2\ 10^{-6}$	89100	**0.11**
4	$1.4\ 10^{-6}$	83700	**0.11**	$1.4\ 10^{-6}$	82800	**0.11**
5	$9.9\ 10^{-6}$	89100	**0.88**	$9.4\ 10^{-6}$	89100	**0.84**
6	$1.4\ 10^{-5}$	89100	**1.20**	$1.8\ 10^{-5}$	89100	**1.59**
7	$6.9\ 10^{-5}$	88200	**6.06**	$6.9\ 10^{-5}$	88200	**6.10**

Determination of the volume of bed material using Wilcock and Crowe simulation results



- The event-based percentage of mobile particles (P_{mevb}) is equal to 4, 17 and 24 respectively for the 1st, the 2nd and the 6th flood events [10]: higher values of L_{m_1} (and L_{m_2}) corresponded to higher values of P_{mevb}. Concerning simulation results, it was not possible to estimate P_{mevb}, but the volume of bed material (*V*) could be evaluated. Higher values of *L* corresponded to higher values of *V*.

Conclusions – This study employed the Meyer-Peter Müller and Wilcock and Crowe models within the HEC-RAS modelling framework to evaluate the representativeness of event-based estimates of sediment transport and bed material transport distances. Results were compared to three-year (2011-2013) field sampling campaign where in-situ bedload and inter-event particle tracking had occurred. Results showed that the Wilcock and Crowe transport model represented the poorly graded gravel bed channel conditions over the range of flows inventoried. Mean bed material transport distances using the Wilcock and Crowe model (0.12 m < L < 5.7 m and 0.11 m < L < 6 m, considering respectively step-wise discharge and unsteady flow simulations) compared relatively well against field observations (0.1 m < L < 3.5 m) and in some instances overestimated travel distances. Findings from this study reinforce the importance of accounting for clast interactions in transport estimates. The Wilcock and Crowe model accounts for bulk inter-particle interactions (e.g. hiding and sand-dependent gravel transport) and the armor layering effects [11]. These could not be accounted for using the Meyer-Peter Müller equation, which could not be correlated to the field conditions and bed material gradation. The comparison of simulated transport distances against available field observations also provides another mechanism to validate appropriate transport equations; particularly where in-situ bedload sampling may not be available.

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