

SEDIMENT ROUTING IN BEDROCK-CONTROLLED CHANNELS

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DECLARATION

I declare that this thesis is my own, unaided work. It is being submitted for the Degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University.

(Signature of Candidate)

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ABSTRACT

A sediment budget model in which each steady discharge scours sediment along a trajectory towards ultimate target storage or deposits sediment towards the same ultimate target storage has been conceptualized and developed. The method is aimed at routing sediment in morphologically diverse bedrock-controlled channels in which sediment transport and storage is not a continuous process in space and time and mostly occurs in response to discrete discharges. The relative value of the ultimate stable scour depth (H_{uss}) for each steady discharge with respect to the current scour depth after adding sediment supply determines the potential to scour or store sediment.

Scour depths measured at discrete locations along the longitudinal profile of a laboratory pool at discrete times until changes in scour were not discernible for each steady discharge and sediment size have been integrated to provide the H_{uss} and storage depletion curve. The experimentally established dependence of scour depth on critical flow depth, settling velocity and sediment supply formed the basis of generating dimensionless H_{uss} and storage depletion curve from these parameters using the Buckingham π theorem. The optimization of experimental results to generate the storage depletion curve gave the exponent of time (ϕ) and the exponential decay factor (k) as 0.5 and 0.0040207 respectively. Regression fit of dimensionless H_{uss} and critical flow intensity gave a linear relationship with a gradient of 0.90214, y-intercept of -1.4766 and R^2 of 96%.

The suitability of the model for budgeting sediment dynamics in a series of connected storage units, the validity of using the relative values of H_{uss} and the current scour depth after adding sediment supply to determine scour potential and the existence of active storage associated with sediment supply for each steady discharge have been confirmed experimentally. Modelling with equivalent steady discharges computed from unit stream power principles on the rising and the falling limbs of the hydrograph resulted in scour on the rising limb of magnitude dependent on the magnitude and sequence of the flood event, and less or no scour on recession. The modelling concepts and approach have thus

been validated and the potential to reasonably simulate sediment storage changes in bedrock-controlled rivers demonstrated.

Key words: Bedrock-controlled channels, sediment routing, scour depth, active storage.

This thesis is dedicated to my wife Lilian, my daughter Winnie, and my sons Steve, Eugene and Brian. Their patience, tolerance and enduring the loneliness can only be rewarded by God the almighty

To my mother Phelgona and Aunt Dorcas who have kept on hoping

In loving memory of my father James and my uncle Henry who saw the start but never
lived to see the end

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A16	Ultimate stable scour depth for Q_w of 6.9 litres/sec and D_{50} of 1.15 mm	A.8
A17	Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 1.15 mm	A.9
A18	Ultimate stable scour depth for Q_w of 8.4 litres/sec and D_{50} of 1.15 mm	A.9
A19	Ultimate stable scour depth for Q_w of 6.9 litres/sec and D_{50} of 0.775 mm	A.10
A20	Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 0.775 mm	A.10
A21	Ultimate stable scour depth for Q_w of 8.4 litres/sec and D_{50} of 0.775 mm	A.11
B1	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 0 – 1 hours)	B.1
B2	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 1 – 2 hours)	B.1
B3	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 2 – 4 hours)	B.2
B4	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 4 – 6 hours)	B.2
B5	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 6 – 8 hours)	B.3
B6	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 8 – 12 hours)	B.3
B7	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 12 – 16 hours)	B.4
B8	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 16 – 29 hours)	B.4

B9	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 29 – 41 hours)	B.5
B10	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 41 – 57 hours)	B.5
B11	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 57 – 63 hours)	B.6
B12	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 63 – 69 hours)	B.6
B13	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 69 – 83 hours)	B.7
B14	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 83 – 89 hours)	B.7
B15	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 89 – 103 hours)	B.8
B16	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 103 – 109 hours)	B.8
B17	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 0 – 1 hours)	B.9
B18	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 1 – 2 hours)	B.9
B19	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 2 – 4 hours)	B.10
B20	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 4 – 6 hours)	B.10
B21	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 6 – 8 hours)	B.11
B22	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 8 – 12 hours)	B.11
B23	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 12 – 24 hours)	B.12
B24	Storage depletion data (Q_w : 7.5 litres/sec;	B.12

	D ₅₀ : 0.775 mm; Measuring times range: 24 – 38 hours)	
B25	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 38 – 55 hours)	B.13
B26	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 55 – 74 hours)	B.13
B27	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 74 – 86 hours)	B.14
B28	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 0 - 1 hours)	B.14
B29	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 1 - 2 hours)	B.15
B30	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 2 - 4 hours)	B.15
B31	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 4 - 6 hours)	B.16
B32	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 6 - 8 hours)	B.16
B33	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 8 - 13 hours)	B.17
B34	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 13 - 27 hours)	B.17
B35	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 27 - 45 hours)	B.18
B36	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 45 - 59 hours)	B.18
B37	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 59 – 76.2 hours)	B.19
B38	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 0.775 mm; Measuring times range: 76.2 – 100.2 hours)	B.19
B39	Storage depletion data (Q _w : 6.9 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 0 – 1 hours)	B.20

B40	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 1 – 2 hours)	B.20
B41	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 2 – 6 hours)	B.21
B42	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 6 – 20 hours)	B.21
B43	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 20 – 48 hours)	B.22
B44	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 48 – 69 hours)	B.22
B45	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 69 – 116 hours)	B.23
B46	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 116 – 124 hours)	B.23
B47	Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 124 – 138 hours)	B.24
B48	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 0 – 1 hours)	B.24
B49	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 1 – 2 hours)	B.25
B50	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 2 – 4 hours)	B.25
B51	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 4 – 6 hours)	B.26
B52	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 6 – 8 hours)	B.26
B53	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 8 – 12 hours)	B.27
B54	Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 12 – 24 hours)	B.27
B55	Storage depletion data (Q_w : 7.5 litres/sec;	B.28

	D ₅₀ : 1.15 mm; Measuring times range: 24 – 39 hours)	
B56	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 39 – 57 hours)	B.28
B57	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 57 – 87 hours)	B.29
B58	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 87 – 107 hours)	B.29
B59	Storage depletion data (Q _w : 7.5 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 107 – 131 hours)	B.30
B60	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 0 – 1 hours)	B.30
B61	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 1 – 2 hours)	B.31
B62	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 2 – 4 hours)	B.31
B63	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 4 – 6 hours)	B.32
B64	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 6 – 8 hours)	B.32
B65	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 8 – 12 hours)	B.33
B66	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 12 – 23 hours)	B.33
B67	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 23 – 32 hours)	B.34
B68	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 32 – 49 hours)	B.34
B69	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 49 – 61 hours)	B.35
B70	Storage depletion data (Q _w : 8.4 litres/sec; D ₅₀ : 1.15 mm; Measuring times range: 61 – 79 hours)	B.35

B71	Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 79 – 96 hours)	B.36
B72	Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 96 – 100 hours)	B.36
C1	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	C.1
C2	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	C.1
C3	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4 hours)	C.2
C4	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4-6 hours)	C.2
C5	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6-8 hours)	C.3
C6	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8-12 hours)	C.3
C7	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12-23 hours)	C.4
C8	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 23-38 hours)	C.4
C9	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 38-57 hours)	C.5
C10	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 57-71 hours)	C.5
C11	Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 71-95 hours)	C.6
C12	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	C.6
C13	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	C.7

C14	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4.08 hours)	C.7
C15	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4.08-6.08 hours)	C.8
C16	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6.08-8.08 hours)	C.8
C17	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8.08-12.08 hours)	C.9
C18	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12.08-20.08 hours)	C.9
C19	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 20.08-30.08 hours)	C.10
C20	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 30.08-45.08 hours)	C.10
C21	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 45.08-60.08 hours)	C.11
C22	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 60.08-80.08 hours)	C.11
C23	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 80.08-98-16 hours)	C.12

C24	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 98.16-103.16 hours)	C.12
C25	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 103.16-118.16 hours)	C.13
C26	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 118.16-131.16 hours)	C.13
C27	Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 131.16-149.16 hours)	C.14
C28	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	C.14
C29	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	C.15
C30	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4 hours)	C.15
C31	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4-6 hours)	C.16
C32	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6-8 hours)	C.16
C33	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8-12 hours)	C.17
C34	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12-21 hours)	C.17
C35	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 21-32 hours)	C.18
C36	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 32-47 hours)	C.18
C37	Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min;	C.19

	D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 47-62 hours)	
C38	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 62-78 hours)	C.19
C39	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 78-96 hours)	C.20
C40	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min shut at 96.16 hours; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 96-100 hours)	C20
C41	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min shut at 96.16 hours; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 100-110 hours)	C21
C42	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min shut at 96.16 hours; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 110-127 hours)	C21
C43	Active storage data (Q _w : 2.85 litres/sec; Q _s : 2.5 ml/min shut at 96.16 hours; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 127-144 hours)	C22
C44	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	C.22
C45	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	C.23
C46	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 2-4 hours)	C.23
C47	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 4-6 hours)	C.24
C48	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 6-8.08 hours)	C.24
C49	Active storage data (Q _w : 2.85 litres/sec; Q _s : 7.3 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 8.08-12.08 hours)	C.25

C50	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12.08-20.08 hours)	C.25
C51	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 20.08-36.08 hours)	C.26
C52	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 36.08-53.08 hours)	C.26
C53	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 53.08-69.08 hours)	C.27
C54	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 69.08-84.58 hours)	C.27
C55	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 84.58-100.58 hours)	C.28
C56	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 100.58-104.58 hours)	C28
C57	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 104.58-117.58 hours)	C29
C58	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 117.58-131.58 hours)	C29
C59	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 131.58-147.92 hours)	C30
C60	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at	C30

	100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 147.92-165.92 hours)	
C61	Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 165.92-170.92 hours)	C31
D1	Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	D.1
D2	Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	D.1
D3	Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4 hours)	D.2
D4	Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; ends and 3.3 litres/sec starts at 5.08 hours Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4-5.58 hours)	D.2
D5	Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 5.58-6.58 hours)	D.3
D6	Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6.58-8.08 hours)	D.3
D7	Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8.08-10.16 hours)	D.4
D8	Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 10.16-12.66 hours)	D.4
D9	Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec;	

	Q _s : 0.00 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 12.66-14.66 hours)	D.5
D10	Stepped discharge hydrographs scour data (Q _w : 1.73 litres/sec; Q _s : 0.00 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 14.66-16.66 hours)	D.5
D11	Stepped discharge hydrographs scour data (Q _w : 1.73 litres/sec; Q _s : 0.00 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 16.66-17.66 hours)	D.6
D12	Stepped discharge hydrographs scour data (Q _w : 1.73 litres/sec; Q _s : 1.8 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)	D.6
D13	Stepped discharge hydrographs scour data (Q _w : 1.73 litres/sec; Q _s : 1.8 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)	D.7
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D16	Stepped discharge hydrographs scour data (Q _w : 3.3 litres/sec; Q _s : 1.8 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 6.43-7.43 hours)	D.8
D17	Stepped discharge hydrographs scour data (Q _w : 3.3 litres/sec; Q _s : 1.8 ml/min; D ₅₀ : 0.775 mm; b: 100 mm; Measuring times range: 7.43-8.93 hours)	D.9
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D19	Stepped discharge hydrographs scour data (Q _w : 3.3 litres/sec;	

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E3	Experimental data on movement of sediment in a series of pools (Pool 1; Q _w : 11.1 litres/sec; D ₅₀ : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.1
E4	Experimental data on movement of sediment in a series of pools (Pool 1; Q _w : 11.1 litres/sec; D ₅₀ : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	E.2
E5	Experimental data on movement of sediment in a series of pools (Pool 1; Q _w : 11.1 litres/sec; D ₅₀ : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)	E.2

E6	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.2
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E9	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)	E.3
E10	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)	E.4
E11	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)	E.4
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	0-1 hours)	
E14	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)	E.5
E15	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.5
E16:	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	E.6
E17	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)	E.6
E18	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.6
E19	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-23 hours)	E.7
E20	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 23-37 hours)	E.7
E21	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm;	E.7

	b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)	
E22	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)	E.8
E23	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)	E.8
E24	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 87-96 hours)	E.8
E25	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)	E.9
E26	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)	E.9
E27	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.9
E28	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	E.10

E29	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8hours)	E.10
E30	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.10
E31	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-23hours)	E.11
E32	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 23-37 hours)	E.11
E33	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)	E.11
E34	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)	E.12
E35	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)	E.12
E36	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range:	E.12

	87-96 hours)	
E37	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)	E.13
E38	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)	E.13
E39	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.13
E40	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	E.14
E41	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)	E.14
E42	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.14
E43	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-25 hours)	E.15
E44	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm;	E.15

	b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)	
E45	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)	E.15
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E47	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)	E.16
E48	Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)	E.16
E49	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)	E.17
E50	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)	E.17
E51	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.17
E52	Experimental data on movement of sediment in a series	E.18

	of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	
E53	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)	E.18
E54	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.18
E55	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-25 hours)	E.19
E56	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)	E.19
E57	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)	E.19
E58	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 53-69 hours)	E.20
E59	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)	E.20

E60	Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)	E.20
E61	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)	E.21
E62	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)	E.21
E63	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)	E.21
E64	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)	E.22
E65	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)	E.22
E66	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)	E.22
E67	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range:	E.23

	12-25 hours)	
E68	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)	E.23
E69	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)	E.23
E70	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 53-69 hours)	E.24
E71	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)	E.24
E72	Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)	E.24

LIST OF SYMBOLS AND ABBREVIATIONS

a	Coefficient of the squared term in the sediment supply layer equation
a_0, a_1 and a_2	Exponents of repeating variable w in Buckingham π s
A	Channel wetted cross-sectional area
A'	Cross-sectional area at time $t-\Delta t$
A_a	Wetted cross-sectional area associated with the average stage, $(h_{ri}+h_{pr})/2$
A_{ff}	Cross-sectional area at the end of the falling hydrograph limb
A_{pf}	Area associated with the peak discharge on the falling limb of the hydrograph
A_{pr}	Area associated with the peak discharge on the rising limb of the hydrograph
A_{ri}	Cross-sectional area at the beginning of the rising hydrograph limb
A_{scr}	Area of scoured layer of sediment
A_{top}	Cross-sectional area of the top of the channel filled with sediment
α	Energy coefficient
b	Width of the channel
b_0	Exponent of repeating variable y_c in Buckingham π
b_1 and b_2	Exponents of repeating variable g in Buckingham π s
BA	Bedrock anastomosing
β	Number of iterations
BR	Braided
c	Kinematic wave velocity
C	Chézy coefficient

c^*	Coefficient of the linear term in the sediment supply layer equation
d	Total derivative of
d^*	Constant term in the sediment supply layer equation
dx	Change in distance in the direction of flow
D	Water surface elevation above a datum plane
D_{50}	Median sediment particle size
D^*	Representative sediment grain (particle) size
D_{pr}	Peak hydraulic depth on the rising hydrograph limb
∂	Partial derivative of
∂h_s	Change in water surface elevation during the Δt time interval
ΔS	Change in sediment storage
Δt	Computational time step
$\Delta \sqrt{t}$	Difference in square roots of successive cumulated scour times
Eq.	Equation
f	A function of
Fig.	Figure
F_s	Entrainment function
g	Gravitational acceleration
g_b	Bed load transport per unit channel width
γ	Specific weight of water
h	Hydraulic depth of flow
h'	Stage at time $t - \Delta t$
h_c	Channel depth
h_{ff}	Final falling hydrograph limb stage
h_{pf}	Peak stage corresponding to the falling hydrograph limb
h_{pr}	Peak stage at the end of the rising hydrograph limb

h_{ri}	Stage at the beginning of the typical flood on the rising hydrograph limb
H	Scour depth
H_{beg}	Previous sediment scour depth plus sediment supply
$H_{fullcap}$	Scour depth of sediment full channel
$H_{(i)}$	Scour depth at time t_i
$H_{(i+1)}$	Scour depth at time $t_{(i+1)}$
H_{init}	Initial scour depth
H_{max}	Maximum sediment scour depth or weir height
H_{new}	New sediment scour depth
H_{prev}	Previous sediment scour depth
H_{sup}	Sediment supply scour depth
H_t	Actual sediment scour depth at the end of routing
H_t'	Scour depth at temporary storage state or fill scour depth
H_{t-1}	Scour depth at time $t-1$
H_T	Total head (energy)
H_{uss}	Ultimate stable scour depth
H_{ussA}	Scour depth of ultimate active sediment storage
$H_{uss}(h)$	Ultimate stable scour depth when there is high sediment supply
$H_{uss}(l)$	Ultimate stable scour depth when there is low or no sediment supply
i	Time location
k	Exponential decay parameter
L	Length as a fundamental dimension for any variable
L_c	Length of the channel
L_{eff}	Effective longitudinal sediment scour length
L_{eff}'	Effective longitudinal sediment supply length
L_{max}	Maximum longitudinal length of sediment storage unit

L_{mw}	Meander wavelength
L_{t-1}	Longitudinal sediment length before sediment supply enters for routing
L_t'	Longitudinal sediment length corresponding to transitory storage state
λ	Ratio of the maximum kinematic wave velocity to the water velocity
m	Total number of fundamental dimensions in all the variables
M	Mass as a fundamental dimension for any variable
MA	Mixed anastomosing
n	Manning's roughness Coefficient
n^*	Number of variables of dimensionally homogeneous equation
p	Number of dimensionless groups (π groups)
ϕ	Exponent of elapsed time
π	Constant
PR	Pool-rapid
q	Discharge per unit width
Q_c	Local transport capacity
Q_s	Bed load discharge
Q_{sin}	Sediment supply
Q_{sout}	Sediment output
Q_w	Water Discharge
Q_w'	Discharge at time $t-\Delta t$
Q_{w1}	Steady discharge Q_{w1} at elapsed time t_1
Q_{w2}	Steady discharge Q_{w2} at elapsed time t_2
Q_{wfes}	Model equivalent steady discharge on the falling hydrograph limb
Q_{wff}	Final falling hydrograph limb discharge
Q_{wo}	Discharge at steady uniform flow

Q_{wp}	Peak discharge
Q_{wres}	Model equivalent steady discharge on the rising hydrograph limb
Q_{wri}	Discharge at the beginning of the rising hydrograph limb
r	Ratio of the channel bottom slope to the average water surface slope
R	Hydraulic radius
R^2	Correlation coefficient
ρ	Density of water
ρ_s	Sediment grain density
SC	Storage cell
S_e	Energy gradient (slope)
S_{ef}	Energy slope on the falling hydrograph limb
S_{er}	Energy slope on the rising hydrograph limb
S_f	Friction slope
S_o	Channel bottom (bed) slope
S_s	Specific gravity of sediment particles
ST	Single thread
S_w	Water surface slope
$\sqrt{t}$	Square root of integrated time since the beginning of routing
t	Time elapsed, or rise, fall or no-event duration
t_i	Time at time location indicator i
$t_{(i+1)}$	Time at time location indicator $(i+1)$
t_1	Elapsed time corresponding to steady discharge Q_{w1}
t_2	Elapsed time corresponding to steady discharge Q_{w2}
t_{fall}	Falling hydrograph limb duration
t_{rise}	Rising hydrograph limb duration
T	Time as a fundamental dimension of any variable
TC	Translation cell

TCL	Translation cell length
T_{fall}	Time interval from peak stage until final falling stage in days
T_{rise}	Time interval from beginning of rise in stage to peak stage in days
T_t	Translation time
τ	Shear stress
τ_o	Threshold stress for sediment movement
u^*	Shear velocity
v	Water velocity
v_c	Critical velocity of flow
v_s	Sediment velocity
V_{rout}	Sediment output volume after each time step routing
V_{sup}	Volume of the incoming sediment supply
w	Settling velocity
ω	Unit stream power
x	Distance along the channel
y	Depth of flow
y_c	Critical depth of flow
y_o	Uniform flow depth
z	Vertical distance of the channel bottom above the datum

CHAPTER ONE

INTRODUCTION

1.1 Statement of problem and motivation to develop new modelling approach

Modelling sediment storage changes in bedrock-controlled channels, which is the subject of this thesis, requires the understanding of the flow complexities in such channels. Bedrock-controlled channels (constituted of bedrock and alluvial reaches) have flow profiles that are highly disturbed by bedrock irregularities and discrete alluvial deposits (bars) and are therefore characterized by highly variable flows within short spatial and temporal resolutions. Because of such flow complexities, solutions derived on the basis of conventional models of sediment transport and storage based on the Saint-Venant equations together with the sediment continuity equation may not be accurate representations of the bedrock-controlled systems sediment dynamics behaviour. The solutions of such conventional models are governed by a number of simplifying assumptions. The assumptions are based on predictable flow characteristics and sediment input regime, which are oversimplifications. Improved resolution results may only be achieved if detailed temporal and spatial changes in flow profiles are correctly represented in the model.

The conventional sediment continuity equation in which sediment transport equations may be incorporated for sediment budgeting may be partial differential in nature. The partial differential equations are intended to provide high-resolution solutions based on infinitesimal time and space steps over some specified period of time for a given channel reach. The general assumption here is that there is temporal and spatial continuity in sediment transport and storage. Thus the structure of these models requires availability of sediment for transport at all sections (James *et al.*, 1996) and at all times. Since sediment may not be available at all sections in bedrock-controlled channels over the entire modelling time step, modelling on the basis of infinitesimal space step and time step over

the entire historical flow duration and the entire length of the river can be numerically unstable.

Thus, model solutions generated at small time steps over the entire historical flow duration that has event and non-event periods apart from requiring excessive computational memory may produce spurious values over periods of no sediment transport. Such detailed models have been known to wander off (show instability) when run for long periods of time or over long river reaches. The data for calibration and validation of such models is also mostly inadequate, as it is fairly expensive to monitor geomorphic changes in the river over many cross-sections for a long time.

A number of studies have revealed that sediment transport and storage are episodic and only occur as responses to discharge events with the potential to erode or store sediment (Neill, 1987; Meade, 1985; Nicolson, 1999; Heritage and Van Niekerk, 1995; Meade *et al.*, 1981; among others). Episodic evolution of fluvial landforms associated with discrete flood magnitudes has also been reported in the Todd River in arid Central Australia (Bourke and Pickup, 1999). The episodic evolution in the latter study was linked to discrete events of extreme magnitudes (flood flows).

Geomorphologic studies of semi-arid South African rivers and arid Central Australian rivers point to the fact that sediment transport and storage in bedrock-controlled semi-arid and arid rivers are episodic. This is because the rainfall events that principally recharge these rivers are rare and extreme in magnitude. The rivers therefore remain stable with no significant geomorphic change after the impact of the last significant event recedes until the next significant event occurs. The term significant event is used to denote an event with the potential to erode and transport sediment. This means that models of geomorphic change in semi-arid and arid areas could be constructed on the basis of discrete discharge events with the potential to cause discernible geomorphic changes. It is important to note that even alluvial channels (gravel bed) in humid areas only respond to significant events. The difference with arid and semi-arid areas is that such significant events happen more frequently in humid areas.

Neill (1987) reported the occurrence of bed sediment transport in short flood episodes widely spaced in time. A model built on the basis of such discrete flood episodes must account for the differences in the characteristics of such flood episodes. In particular the flood episodes differ in discharge magnitudes and duration and also enter or are available at different levels of sediment storage availability in the different reaches of the river. This means the individual flood episodes have different sediment transport and storage potential. A model built at the time scale of these episodes would be desirable, as it would reduce the amount of data to be monitored for calibration and validation. This is because it will only be important to monitor sediment movement when an event occurs.

Depending on the resolution required of the model results, either a more detailed or a less detailed model solution can be generated at the event scale. The detailed resolution model (small time step) can be applied or built within the duration in which an individual event causes geomorphic change in the river to minimize spurious values over non-discernible geomorphic change periods. It is important to note that detailed resolution partial differential equations of sediment transport can embody the episodic concept and work more efficiently if modified to separate periods with flood episodes capable of causing discernible geomorphic change from those that cause non-discernible changes. This means the model must distinguish significant event periods that require detailed resolution treatment from non-event or insignificant event period that does not require the same treatment. It must, however, be remembered that parameter estimation for partial differential models in bedrock-controlled rivers are strongly militated against by factors such as morphological complexity and other resistance features such as vegetation establishment in the river.

The downstream transfer of sediment in transport limited channels such as bedrock-controlled channels commonly shows discontinuities due to concentrated inputs and pronounced tendencies for transport or storage of sediment in particular reaches (Church, 1983; Kelsey, 1987). In particular, the extreme event magnitudes in arid and semi-arid areas have been shown to result in episodic sediment supply in the regional rivers (Bourke and Pickup, 1999; Heritage *et al.*, 1999). Thus sediment transport model

developed for bedrock-controlled channels other than being episodic must also account for variations in sediment supply and channel morphology.

River managers identified increased sediment supply in the bedrock-controlled Sabie River, which is the inspiration of this study, prior to the catastrophic flood of the year 2000, which stripped the river channels of sediment. The increased sediment supply resulted in increased sediment storage in the river channels and posed pervasive threat to conservation. The increase in sediment storage changed the streambed character from a diverse mixture of bedrock and alluvial habitats to a more homogeneous alluvial habitat with much reduced bio-diversity. Thus there is need to develop a modelling method suitable for predicting sediment dynamics in bedrock-controlled rivers for purposes of inferring in-channel habitat change in response to specific flood episodes. Such a model may simply be based on sediment storage changes associated with discrete flood events of different magnitudes and duration in specific sediment storage geometries. The prediction of sediment storage changes, however, requires the understanding and modelling of the interactive role played by discharge, channel morphology, sediment supply, sediment characteristics, sediment hydraulics and the local flow hydraulics.

The process of investigating the river system's sediment storage change behaviour may involve use of a laboratory model of the prototype in which the factors governing sediment transport and storage dynamics interact or field prototype study. Laboratory models have been found particularly useful for studying sediment storage change dynamics in river channels with complex morphology such as braided channels.

1.2 Sediment dynamics and geomorphic response

River systems have two disequilibrium modes of geomorphic change, erosion and deposition, and one equilibrium mode experienced during the periods of no net change in variable interaction (Bull, 1991). Erosion and deposition are therefore important indicators of geomorphic change. In practice, river systems rarely attain a state of no net change in geomorphology (equilibrium) except the rate of change may increase or

decrease towards the ultimate stable state depending on the energy content or the quantity of the event responsible for geomorphic change. The event responsible for geomorphic change may be discharge episode or sediment supply.

Modelling the geomorphic response of the river requires modelling the changes in the geomorphic processes of erosion and deposition in response to the movement of water and sediment at the appropriate geomorphic scale. This is because erosion and deposition at any geomorphic type scale are dependent on the hydraulics of water discharge and sediment discharge. Geomorphic type scales considered as spatial modelling units in this thesis occur in a hierarchy of declining spatial scales of reaches, channel types and/or morphologic units. The fineness or coarseness of the scales used in modelling is dependent on the resolution required of the model results. The resolution required of the model results depends on the purpose of the model.

Channel morphology influences the effectiveness of discharge in transporting sediment. The morphological variations in bedrock-controlled rivers either accelerate or decelerate erosion and deposition processes. For example, bedrock outcrop features while acting as controls back up the flow and cause sediment deposition in the upstream pool (Fig. 1.1). The bedrock features also act as constrictions to flow in their immediate vicinity and lead to expansion downstream causing erosion and deposition respectively. The lee deposits also result from the separation.

Theoretically, if sediment supply is limiting, erosion occurs to make up for the limited supply provided the transport capacity is greater than the supply and sediment is available in the channel. Deposition occurs when the transport capacity is less than the supply.

Sediment transport capacity is greater than sediment supply in bedrock streams (Montgomery *et al.*, 1996). Thus sediment transport capacity may not be limiting in bedrock-controlled channels. Sediment transport capacity is the maximum load a given discharge event can carry. It depends on the slope of the stream; the discharge; the velocity, shape, size, and specific gravity of the materials transported; the ratio of depth

of water to width of stream; and the degree of mixing of materials (Gilbert, 1917). Some of these factors are dependent on each other.



Figure 1.1: An example of bedrock-sediment association from Sabie River, South Africa

1.3 Linking in-channel geomorphic change to biodiversity

The sustenance of *flora* and *fauna* in the river environment is dependent on the availability of suitable physical habitat template and hydraulic conditions. The physical habitat template may be composed of either alluvium or bedrock or both.

In the management of physical habitat template of alluvial and bedrock rivers, it is important to explore the influence of geomorphic response resulting from the interactive factors of geomorphic change. This is conceptually illustrated in Fig. 1.2 that shows how geomorphic processes of change derived from the interactive factors ultimately affect the physical habitat template and *floral* response. The geomorphic change resulting from the interaction of flow and sediment available provide habitats for a wide range of species (Brookes, 1988; Poff *et al.*, 1997) within specific geomorphic types. Sediment movement and deposition results in change in physical habitat template. Vegetation responds to changes in physical habitat template and local flow hydraulics and feeds back through resistance to flow and sediment movement. Vegetation affects physical habitat

template directly by restraining movement of the bed material and hydraulically through resistance to flow.

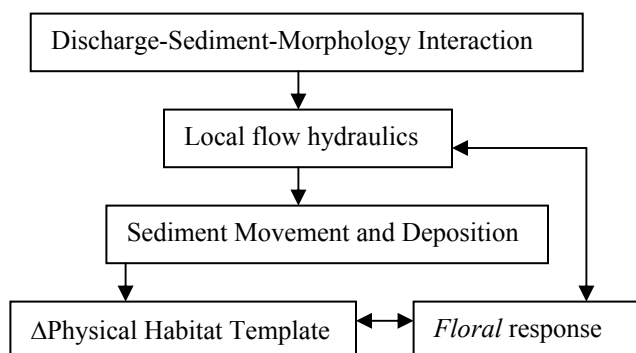


Fig. 1.2: Conceptual linkages of interactive processes of sediment movement and storage to physical habitat template and floral response in river systems.

Non-alluvial features such as bedrock outcrops accelerate the formation of certain habitats. The non-alluvial features obstruct flow by acting as dams or weirs, and thus create pool habitats for aquatic organisms. For instance, the removal of woody debris in Bridge Creek in the Coast Range of northern California interfered with local flow levels and sediment storage compartments known to provide diverse habitat conducive to anadromous fish reproduction (Klein *et al.*, 1987). The absence of non-alluvial features leads to more rapid transfer of sediment through the channel system and a reduction in the stable substrates and depositional sites. The consequence would be a bedrock channel with limited potential to support biotic species that rely on alluvial matter as their habitat.

The high diversity of habitat and species in bedrock-controlled rivers, particularly the Sabie River, in South Africa is the result of mixed bedrock/alluvial nature of the rivers (Rogers and Bestbier, 1997; Rogers and Biggs, 1999). Increased sediment storage reduces bedrock influence and homogenizes the system (Rogers and Biggs, 1999) resulting in reduction of species that thrive under bedrock influence. An example of bedrock species is *Breonadia salicina* vegetation type (Van Coller *et al.*, 1997). Thus the bed and diverse flow conditions provided by alluvial and non-alluvial features in bedrock-controlled channels other than acting as stream habitats for fish and other aquatic

life, can also influence their proliferation negatively depending on the magnitude of sedimentation. For example, fisheries resources are often adversely affected by increased sedimentation (Chapman, 1961; Hall and Krygier, 1967; Phillips, 1971; Lisle, 1982). Ideally fisheries require deep, shaded pools interspersed between riffle sections (Neill and Hey, 1982). Lisle (1982) gives an account of the diminished species of anadromous salmonids in Northern California as a consequence of the deterioration of habitat due to sedimentation. Heavy sedimentation diminished riffle-pool sequences, which are known to provide the cover and diversity of substrate, and hydraulic conditions that meet the various requirements of life stages of salmon and trout. The removal of riffles deprives anadromous fish of suitable spawning habitats (Neill and Hey, 1982). In a related study, Keller and Tally (1979) noted that sediment pollution and subsequent loss of habitat diversity in streams flowing in Coastal Redwood Forest in Northern California where the effect of large organic debris was heavily felt had adversely affected anadromous fish population. The barriers and heavy sedimentation also physically constrain the fish migration.

Geomorphic change is therefore synonymous with habitat change, which is a pivotal river management concern with important implications on biotic species. Geomorphic change at the appropriate geomorphic type scale if correlated with the adaptations of the diverse biotic communities, can improve the understanding of the influence of geomorphic change on ecological functions of such river systems and aid formulation and solution of appropriate predictive models.

The understanding of the interaction of water and sediment at the geomorphic type scale of consideration and predicting geomorphic response can aid formulation of process based management protocols that can accommodate economic uses while protecting ecosystem functions. This is important because humans have continued to exploit rivers for economic purposes at the expense of their ecological function. In the words of Naiman et al. (1995) and NRC (1992), many rivers no longer support socially valued native species or sustain healthy ecosystems.

1.4 Underlying assumptions

The underlying assumptions or premises in this research include.

- Bed load sediment transport and storage depends on morphology, sediment available in the channel and/or sediment supply, sediment characteristics and the magnitude and duration of individual discharges.
- Processes of geomorphic change, i.e. erosion and deposition, do not necessarily progress evenly through time, but are episodic in nature, with periods of stability separated by relatively unstable periods of geomorphic change.
- The scale of resolution of the model is dependent on the purpose of the model.

1.5 Hypotheses

The main hypothesis of this research is that sediment transport and storage is not a continuous process in space or time but occurs in response to discharge episodes each of which erodes sediment along a trajectory towards an ultimate target storage or stores sediment towards the same ultimate target storage.

1.5.1 Specific hypotheses

The specific hypotheses of this research include.

- The spatial distribution of sediment in bedrock-controlled rivers varies with the storage unit type.
- Individual discharge episodes erode sediment along a trajectory (storage depletion curve) towards some definable ultimate stable state or store sediment towards the same ultimate stable state.
- The storage depletion curve and ultimate stable state of sediment storage for individual discharges are dependent on sediment supply.
- A sediment budget model constructed on the basis of sediment storage changes associated with constant or discrete discharges of specific magnitudes and duration

and which also accounts for sediment supply is appropriate for routing sediment in each of the different storage units of bedrock-controlled channels.

- The sediment dynamics in a series of sediment storage units vary with the spatial sequence of each sediment storage unit in the series.

1.6 Objectives

The main objective of this research is to conceptualize, develop and validate an inverted episodic sediment budget approach in which each steady discharge scours sediment along a scour trajectory (storage depletion curve) towards ultimate target storage or deposits sediment towards ultimate target storage in storage units of bedrock-controlled channels.

1.6.1 The specific objectives

The specific objectives of this research include:

- To establish the need for developing sediment routing approach suitable for bedrock-controlled rivers in which river habitat management for ecosystem sustenance is of primary importance.
- To conceptualize and develop the inverted episodic sediment budget modelling approach for bedrock-controlled channels.
- To determine experimentally the sediment scoured up to ultimate stable state by each of a number of steady discharges of different magnitudes for different sediment sizes in a laboratory pool model.
- To determine experimentally the sediment storage change with time for each of a number of steady discharges of different magnitudes for different sediment sizes in a laboratory pool model.
- To use experimental model results to derive the ultimate stable sediment storage state and storage depletion curve non-dimensionally on the basis of sediment characteristics and flow condition in bedrock-controlled channels.
- To investigate the dynamic component of sediment storage (active storage) associated with the sediment supply.

- To apply the inverted episodic sediment budget model to episodically route sediment in a series of pools.
- To confirm the model results experimentally.
- To develop an unsteady flow inverted episodic sediment budget model suitable for routing sediment in storage units of bedrock-controlled channels for typical field unsteady flow conditions.

1.7 Organization of the thesis

The thesis is organised into nine chapters. The current chapter (chapter one) is the introduction, which includes the statement of problem and motivation for research. The linkage between in-channel geomorphic change and biodiversity is presented in this chapter to elucidate how the process-form interactions affect the physical habitat template and the ecology of the river. The chapter ends with the presentation of the hypotheses and the objectives of the study.

Chapter two provides the background to the inadequacies of conventional sediment transport models and factors affecting sediment dynamics and the resulting geomorphic change in bedrock-controlled rivers. The general geomorphological and hydraulic characteristics of bedrock-controlled rivers and those of Sabie River, South Africa in particular are presented to elucidate the uniqueness of sediment transport and storage characteristics of such river systems. Chapter two thus motivates the need to develop new sediment modelling paradigm or approach.

Literature is reviewed to support empirical process-models in geomorphology and the relevant scales of resolution appropriate for modelling sediment movement and storage in bedrock-controlled rivers in chapter three. The inverted episodic sediment budget modelling approach for routing sediment in terms of the storage characteristics (ultimate stable state of sediment storage and storage depletion curve) of discrete discharge events in bedrock-controlled rivers is conceived and explained in the same chapter. The translation concept and the rationale for its introduction in the budgeting of sediment

dynamics in bedrock-controlled rivers have been explained in this chapter. The active sediment storage has been included in this chapter to show the effect of sediment supply rate on the dynamic and ultimate stable storage states.

Chapter four presents the experimental materials and the selection criteria as well as their characteristics of importance (settling velocity) in the context of this research. The experimental methods, equipment, procedures and variables measured that are aimed at determining the scour parameters of ultimate stable scour depth (H_{uss}) and storage depletion curve are presented in this chapter. The same chapter covers experimental methods, procedures, variables measured that are aimed at establishing the effect of sediment supply on H_{uss} and storage depletion curve, confirmation of the inverted episodic sediment budget modelling concept and routing of sediment in a series of pools. The summarised list of experiments performed, conditions tested and the purpose of the experiments is also included in this chapter. All the possible practical experimental limitations that have the potential of lowering the accuracy of the results are discussed in this chapter.

All the experimental results are presented, interpreted and their significance explained in chapter five. These include experiments on:

- (1) Determining the relationship between the ultimate stable scour depth and discharge for different sediment sizes.
- (2) Determining the storage change with time for different sediment sizes and selected constant discharges (storage depletion curve)
- (3) Establishing the effect of sediment supply on storage depletion curve and ultimate stable scour depth for selected constant discharge (active storage)
- (4) Confirming the working of the modelling concept
- (5) Confirming sediment dynamics model in a series of pools

The dimensionless forms of the H_{uss} and storage depletion curve integrating the significant variables that affect sediment storage changes in bedrock-controlled rivers are developed in chapter six. The significant variables of interest include flow condition

(discharge or critical flow depth), sediment characteristics (settling velocity or representative sediment size (D_{50})) and morphological characteristic (channel width). The development of the dimensionless relationships is preceded by the analysis of the experimental data on a pool model to establish the dependence of sediment storage changes on these significant variables affecting sediment dynamics. The dimensionless relationships have been developed theoretically using the Buckingham π theorem. The potential use of the experimentally derived H_{uss} and storage depletion curve as sediment scour parameters in the sediment budget model proposed for bedrock-controlled rivers is also briefly captured in chapter six. The exponential decay of the sediment storage depletion curve towards the H_{uss} proposed in chapter three is confirmed in this chapter.

The inverted episodic sediment budget model for routing sediment in a series of pools characteristic of sediment storage units in bedrock-controlled rivers is developed and verified in chapter seven. The details of the model including its ability to simulate sediment scour and storage as well as its incorporation of the translation module are captured in this chapter. The experimental and model scour depth changes with time in a series of pools are used to demonstrate the sediment storage characteristics of a sequence of storage units. The model and the experimental results for a steady discharge lasting for infinite duration with the series of pools are also used to confirm that both the modelling logic and the parameters of the inverted episodic sediment budget model are realistic for routing sediment in storage units of bedrock-controlled rivers. The effect of sediment supply rates on H_{uss} for the given steady discharge is included in chapter seven where the need to develop the concept of active storage is recommended. A series of steady discharges each stepped up or down after scouring sediment for finite duration are used to validate the use of H_{uss} as a sediment scour potential and hence validate the sediment budgeting concept.

An unsteady flow inverted episodic sediment budget model appropriate for routing sediment in a series of pools formed behind obstructions in bedrock-controlled rivers for unsteady flow situation is developed in chapter eight. The method is built on the same concepts of the H_{uss} and the storage depletion curve developed as dimensionless

parameters in chapter six but in this case the rises and the falls of the discrete discharge hydrographs drive the model. A method for idealising unsteady flow into equivalent steady discharges on the rising and the falling limbs of the discrete discharge hydrographs based on unit stream power principles is developed in this chapter. The routed sediment dynamics in a series of pools using a series of hypothetical discrete discharge hydrographs is consequently presented in this chapter. The need for and how to develop dimensionless H_{uss} and storage depletion curves for different sediment storage units (e.g. channel types) found in natural bedrock-controlled rivers such as the Sabie River have also been explained. The main aim is to show the potential of the inverted episodic sediment budget model in routing sediment in bedrock-controlled rivers at realistic scale of resolution for typical field unsteady flow behaviour.

The final chapter (chapter nine) is on conclusion and recommendations. The conclusion presents the extent to which the study objectives or hypotheses have either been achieved or disapproved. The recommendations highlight the gaps that exist for further research, in particular the need to apply the unsteady flow inverted episodic sediment budget model to simulate sediment dynamics in the different channel types of the Sabie River and other bedrock-controlled rivers. The constraint on further research and development beyond the scope achieved particularly involving application on the Sabie River is shown to have been the result of the time frame and the resources available for monitoring sediment storage changes in the different channel types of the Sabie River.

CHAPTER TWO

BACKGROUND

2.1 Preamble

This chapter reviews the limitations of conventional models of sediment transport in order to put the problem in context and motivate the development of process based numerical models that derive their strength from system characteristics and controlling processes. Such process based numerical models can have predictive potential at the desired scale of resolution, provided the processes considered in building the model are representative of the system's characteristics and behaviour. The interactive processes that control sediment dynamics and the resulting geomorphic change are also discussed to provide the background understanding of the factors to consider in the development of a new modelling approach. While focussing more on the impact of bedrock-controlled rivers environments on flow hydraulics and channel morphology changes, factors that affect sediment dynamics in general, i.e. including purely alluvial reaches, are highlighted.

The general characteristics of bedrock-controlled rivers that influence sediment transport and storage are also presented in this chapter. Further, the characteristics of bedrock-controlled rivers are presented to explain the uniqueness of sediment transport and storage characteristics associated with bedrock-controlled rivers. In particular the different channel types in the bedrock-controlled Sabie River, in South Africa have been shown to have different sediment transport and storage characteristics/potentials.

2.2 The limitations of sediment transport models and the need for an alternative modelling approach

Many sediment transport models were developed in the twentieth century using different sediment transport and hydraulic parameters. The same relationships have been retained

for modelling sediment transport despite their inadequacies. The estimated sediment transport rate from each of the methods has been found to vary significantly. For instance, Poplawski *et al.* (1989) compared the performance of five methods in predicting sediment transport in an inland river in North Queensland and concluded that there is no particular method that can be recommended universally since the scales of variation of their performances were quite significant. The five methods used in the study include those of Ranga Raju (1985), Van Rijn (1984a, b), Engelund and Hansen (1967), Ackers and White (1973).

In most of the second half of the twentieth century, sediment transport experts were concerned with the inadequacies of the sediment transport theory. The other writers who expressed their concern about the conflicting results of sediment transport theories other than Poplawski *et al.* (1989) include Graf (1971), Bogardi (1974), Raudkivi (1976), Simons and Senturk (1977), Ackers (1983), Klingemann and Emmett (1982), Yalin (1972), among others. According to Graf (1971), the discrepancies, as exhibited by such studies, are not very encouraging and leave one to speculate that possibly not all the important factors governing the sediment transport problem are fully understood. Bogardi (1974) notes that in connection with the total transport, relating the results of the models are only approximate due to the neglect of considerable differences. Raudkivi (1976) reproduced comparative diagrams from various sources and concluded that more comprehensive field measurements are essential before much more can be said about the various formulae. This is of course notwithstanding the problems of field measurement as explained later.

Poplawski *et al.* (1989) concluded that specific parameters can be dominant in local conditions and therefore it is desirable to match methods against a preliminary evaluation of site specific data. Simons and Senturk (1977) noted that the bed material load equations are established for different conditions and their use should be restricted to the conditions for which the equations are applicable. Furthermore, according to the latter authors, very few direct measurements of total sediment discharge of rivers have been made. Ackers (1983), referring to straight channels rather than natural rivers, wrote that

even the best of the available theories were only able to assess transport rates from the hydraulic parameters of a channel to a two-fold accuracy for about two-thirds of the data. Poplawski *et al.* (1989), further established that it is almost impossible to predict the bed material load with an accuracy better than a factor of two and consequently recommended application of simple approximation functions in order to avoid the complicated numerical methods. According to Dawdy and Vanoni (1986), unreliable sediment discharge functions and linkages with the geometry, friction and armouring of erodible channels hamper numerical models.

Klingeman and Emmett (1982) compared careful river measurements with common empirically derived equations and concluded that even when the empirical relations agree with each other, they are not well supported by the data. Yalin (1972) explains that given the number of variables involved, transport relationships require a family of surfaces, or a family of families of curves, for adequate graphical representation. He notes that this is strictly for the case of uniform two-dimensional flow: the case of non- uniform three-dimensional river flow he avoids, as presumably too complex to be worth discussing in theoretical terms.

The divergence of theories of sediment transport is clear enough evidence of the divergence of opinion on the mechanics of sediment transport. This problem is compounded by the difficulties of field measurement. The general principle of measuring devices is the trapping and screening of the moving material. None of the trapping devices so far developed has been found to be entirely satisfactory for determining bed load, suspended load or the total load (Dake, 1983). The situation has not changed in the early twenty first century as the same Helley Smith Sampler (0.2 mm-mesh-bag) commonly used for trapping bed load is still used to measure bed load transport. The sampler occasionally gets clogged by larger particles and thus traps particles that are finer than the bed load. There are considerable problems of sampling over space and time. Even if the Helley Smith Sampler is accurate it only captures a snapshot of the total picture and is difficult to use in flood conditions when most of the transport takes place. The problems of measurement are also caused by the complexity of the channels, for

instance complex channel morphologies and uncertainties in the occurrence of flood events. Floods of given magnitudes and recurrence intervals are conventionally predicted with the use of probabilistic concepts that may not be completely reliable. These problems are therefore generally responsible for the scatter of measured data, which sometimes diverge as much as the theories which seek to predict them.

The reviews in the preceding paragraphs clearly indicate that by the second half of the twentieth century, river scientists were more concerned with the inadequacies of sediment transport theories for general application and problems of measuring sediment in rivers. Thus, though similar sediment transport theories have been retained they are, however, restricted to computing sediment transport at specific sites/cross-sections and not suited for evaluation of mean sediment transport rate over the entire length of the river.

Another problem of sediment transport and morphology changes in bedrock-controlled channels results from the fact that sediment transport regimes may appear to be either supply dependent or stream power dependent. Sediment transport regime being sediment supply dependent means it is responsive to volumes of new sediment supplies entering the channel. Sediment transport regime being stream power dependent means that it is responsive to the magnitude of flow and shear stress in the channel. This is a conventional sediment routing problem in situations where some sections of the channel are formed in sediment since the origins of these transport regimes become unclear. Relatively reliable sediment storage and/or transport parameters can therefore be suitably determined in a laboratory model in which the initial conditions, inputs and constraining factors can be controlled.

Due to consensus of opinion on unreliability of sediment transport theory, Neill (1987) notes the desirability of having alternative and supplementary methods of estimating mass transport, independent of hydraulic and mechanical considerations. He outlined some principles that link long term volumetric transport to large-scale changes in channel morphology, both external and internal. According to his recommendation, these principles might be used in some cases to estimate transport from known morphological

changes, and in others to indicate the potential limits of morphological change from known transport rates.

It is important to note that the conventional sediment transport models predict sediment transport by computing the total sediment output from the river reach, catchment, etc. However, if the interest is on channel form and associated habitat, as is the case in this study, it is the storage within the reach, and the distribution of stored sediment, that is of interest.

The interrelationships between sediment transport and channel morphology have not been fully explored in bedrock-controlled channels because of the complexity in behaviour resulting from non-alluvial boundaries (Lisle, 1987). The study corroborates Neill's (1987) recommendation in the preceding paragraph that in a situation where the non-alluvial boundaries cannot allow the self-formation of channels, there is need to de-emphasise sediment transport and river mechanics. Instead mass balances using the age and volume of sediment stored in reservoirs (i.e. channel bed, bars etc.) should be determined. Furthermore, the study notes that the field conditions for directly studying sediment transport in such channels are formidable and this combined with complex and episodic behaviour only favour studies based on laboratory experiments and theoretical development of mathematical models based on physics and probability.

Although the application of laboratory results to field situations can only be partially relied on, it should be noted that this is the most established and viable method of applying basic hydraulic principles to investigate and model fluvial systems behaviour under different morphological and hydraulic conditions. An alternative viable method developed on the basis of qualitative rule based method (Nicolson, 1999) can augment the laboratory efforts.

Development of qualitative rule based method requires a deep understanding of the interactive processes controlling the system behaviour. Qualitative rule-based method is an intelligent systems method that is knowledge based, meaning that it is expert opinion

driven. The expert must therefore have a good knowledge of the system being modelled and its controlling processes and must display a deeper understanding of the modelling principles to be able to formulate rules and states that govern the operation of the qualitative rule based model. Nicolson (1999) demonstrated that with a good understanding of the system's behaviour and governing principles it is possible to use qualitative rule based model to develop an intellectual tool of river management that can qualitatively guide the decision making process. The use of laboratory investigations and qualitative reasoning based on expert opinion can lead to a pragmatic numerical model for predicting sediment movement and storage in bedrock-controlled rivers.

The episodic nature of morphological change that can be demonstrated through the study of rates of sediment accumulation limits the direct determination of mean rates of sediment accumulation. In bedrock-controlled channels, the short spatial scale within which diverse morphological type units occur and the large time scales over which any significant morphology changes occur, makes field studies untenable unless there is major financial backup. This is because of the need to set up monitoring stations at short spatial intervals and over longer periods of time with technical monitoring staff.

Apart from the rate of operation of geomorphological processes being highly variable according to spatial scale and location, it has been established (Ashmore, 1988; Hoey and Sutherland, 1991; Warbuton and Davies, 1994; Kuhnle and Southard, 1988) that the bed load transport and storage is highly variable with time. Bed load transport rates have been found to fluctuate over ranges of time scales even at constant discharges (Kang, 1982; Southard and Smith, 1982). Fluctuations range from 2 to 10 hours in the models, which is equivalent to several tens of hours in the prototype (Ashmore, 1988). Most of these studies were done on laboratory braided models in response to the difficulties experienced with changes in bed morphology in such river systems. Most changes in bed morphology in braided rivers occur at high discharges when the water is turbid, observation is difficult and measurement is almost impossible (Smith, 1974; Hein, 1974; Rust, 1978). Similarly, measurement of bed load transport and bed morphology changes

in a bedrock-controlled natural channel is complicated by the presence of non-alluvial outcrop features.

The fluctuation in bed load transport and storage can be linked to fluctuations in flow hydraulics and sediment input variations. Such variations are primarily the consequence of unsteady, discontinuous sedimentation. The variations are therefore responsible for spatial variability in sediment accumulation. These long-period and spatial fluctuations compound the problems of field measurement of bed load for use in calibration and verification of the models. Furthermore, sediment transport rates are difficult to measure directly in bedrock-controlled rivers where temporal and spatial variation at a river cross-section means that direct point sampling of mobile sediment is likely to bear little resemblance to mean transport volumes (Moon et al., 1997; Birkhead et al., 2000). The study of rates of sedimentation may therefore not yield meaningful results.

What has come out of the review is that conventional methods of computing sediment transport do not yield accurate values of rates of sediment transport. It might be sufficient to model sediment transport and geomorphic change using a sediment budget technique involving estimation of volumes of sediment eroded or deposited (change in storage) in response to episodic events with quantified sediment transport potentials. The use of laboratory models for studying geomorphologic changes is also emphasised.

2.3 Underestimation of sediment supply from the catchment

Attempts that have been made to determine the sediment supply potential of river basins have not yielded accurate results. The models that have been used in such attempts include the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1960) coupled with the sediment delivery ratio (SDR) technique, the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1972) and the Erosion-Deposition Model (EDM) (Khanbilvardi *et al.*, 1983a, b).

The delivery of sediment to the channel or the proportion of sediment exported from a catchment is very difficult to predict accurately as it depends on several factors. Such factors include the density of the sediment, the grain size of the sediments, the storm/runoff characteristics, magnitude and proximity of sediment source to drainage network, the availability of sediment storage areas and catchment characteristics such as mean slope, etc. Thus some of the potential sediment estimated, as eroded from the catchment by methods such as USLE may not reach the channel and only end up being stored in the catchment basin.

Storage of sediment in different locations and for varying lengths of time complicates the process of sediment delivery (Harvey, 1977). For example eroded sediment may be translated within a catchment basin but not exported from it. Such sediment may be stored on terraces and floodplains.

The rate at which sediment is delivered from watercourses in the catchment to the river is usually considerably less than the rate at which it is eroded from the land surface (Vanoni, 1975). A considerable proportion of the material is stored at intermediate locations (Meade *et al.*, 1982) wherever the entrainment capacity of the flow is insufficient to sustain transport (Birkhead *et al.*, 2000). Thus since SDR used to correct the values predicted by USLE is the ratio of sediment that finds its way to a downstream point to the gross erosion from the catchment it cannot be wholly relied on. For example, in a study of river basins in the South- eastern USA, Trimble (1977) found that while upland erosion was progressing at about $9.5 \text{ mm } 1000 \text{ a}^{-1}$ sediment yields at the mouths of catchments were only $0.53 \text{ mm } 1000 \text{ a}^{-1}$. The delivery ratio was thus only 6%, with the difference being stored in valleys/depressions and channels.

The delivery ratio may depend on scale effect. Eroded sediment is commonly delivered directly into the channel in a low order stream, but is held in store in higher order catchments (Goudie, 1995). The scale effect makes it difficult to extrapolate geomorphological rate change determined at one spatial scale to another spatial scale.

The Modified Universal Soil Loss Equation (MUSLE), believed to be more accurate (Williams, 1975) than USLE as it considers independent events and eliminates the need for a separate SDR may not consistently produce good results over a broad spectrum of conditions (Foster *et al.*, 1980; Khanbilvardi and Rogowski, 1984a, b). This is because MUSLE and USLE both lump several complex processes of soil detachment, soil entrainment, transport and deposition, into a single relationship that considers the sediment yield at the watershed outlet basically as a function of detachment and subsequent transport of eroded material (Khanbilvardi and Rogowski, 1984b). The theoretically based EDM considers the processes of detachment, entrainment, transport and deposition in separate relationships and produces improved results (Khanbilvardi and Rogowski, 1984b). However, the accuracy of the results is a function of the grid resolution. For example, extremely fine grid resolution that would have the advantage of accurate results may not be easy to define in large catchments with heterogeneous physical boundaries or landscape (e.g. valleys, hills, etc.).

Thus the estimated sediment yield from watercourses in the catchment is lower than the catchment sediment supply potential to the river. This means that the sediment supply used in sediment transport models is an underestimate. Thus the sediment transport rate computed on the basis of the estimated sediment supply from the catchment cannot be accurate.

2.4 The effect of transport capacity and/or competence, and sediment supply on sediment dynamics

The flow has a significant effect on the morphology of any channel in which there is a moving phase of granular materials. In particular, the magnitude of discharge, and its duration play an important part in channel development. Lane (1955) depicted the relationship between water discharge (Q_w), channel bed slope (S_o), sediment size (D_*), and bed load discharge (Q_s), as:

$$Q_s D_* \propto Q_w S_o \quad (2.1)$$

Thus, if water discharge is abruptly increased relative to bed load sediment discharge and if slope does not immediately change, a stream will react either by entraining more of the bed sediment to meet the increased capacity, or by entraining larger sizes of bed materials to meet the increased competence. Usually both adjustments occur (Shepherd, 1979). To include properties of channel geometry, Schumm (1969, 1971) extended Lane's qualitative relationship to the following form:

$$Q_w \propto \frac{bh_c L_{mw}}{S_o} \quad (2.2)$$

where, b is channel width, h_c is channel depth, and L_{mw} is meander wavelength.

The relationships (Eqs. 2.1 and 2.2) indicate that channels respond to variations in discharge by eroding or depositing and thus changing their widths and depths. However, bedrock channels with rigid bed and banks and which also incorporate bedrock outcrops may only adjust their bed surface profiles (surface depths) and flow profiles (flow depths) as an indication of morphological response resulting from the interaction of water discharge, sediment and non-alluvial features. Meander wavelength and sinuosity may not adjust if the channel walls are rigid, unless there is incision into the rock walls.

Estep and Beschta (1985) in studying transport of bed load sediment and channel morphology at Trap Bay Creek established that supply limitations could influence the relationships between bed load transport and stream discharge. Stream flow was found to be a dominant factor influencing bed load transport during moderate storm events at an upper riffle because the material was readily available for transport. However, transport past a lower riffle was limited, except during and following a storm event of relatively large magnitude. The energy available during small storms was apparently insufficient to transport material through the study reach. Hence, the dynamics of sediment supply and availability of the energy interact in such a manner that sediment transport rates at two locations in a channel may appear to behave independently. Although, according to the study, there appeared to have been a general increase in material transport at Trap Bay Creek, stream flow was only one factor influencing sediment transport. Furthermore, transport appeared to occur in pulses or waves, probably because of differences in

hydraulic conditions and characteristics of the armour layer of the two riffles. The highlighted study points to the fact that sediment availability, the magnitude of discharge events and the physical condition of the channel are important controls in sediment transport and deposition.

A modelling technique in which the sediment transport potential is defined at a stable state of transport is desirable to avoid the effect of sediment waves from marring the definition of a unique physical relationship of sediment transport. This is because the existence of sediment waves introduces wide variations in rates of bed load transport for any given discharge event which makes it difficult to find a unique physical relationship between the interacting variables and define the mean sediment transport rate for the given river.

Alluvial and bedrock morphologies are not permanent conditions of bedrock-controlled fluvial systems. Several processes transiently affect the distribution of bedrock and alluvial reaches in bedrock-controlled fluvial systems. Scour by debris flows, infrequent floods and turbulent episodes, for example, can intermittently convert alluvial reaches to bedrock morphology. Sources of episodic sediment supply such as landslides may introduce and route sediment pulses through bedrock-controlled channel networks, temporarily converting bedrock reaches to alluvial morphologies. Montgomery *et al.* (1996) anticipated that local sources of high sediment supply could result in alluvial reaches within the field of bedrock data and locally reduced supply and increased transport capacity could likewise result in bedrock reaches within the field of alluvial data.

The spatial distribution of bedrock and alluvial reaches therefore depends on the relation of local transport capacity (Q_c) to the bed load sediment supply (Q_{sin}) delivered from upstream and across channel banks (Montgomery *et al.*, 1996). A bedrock streambed indicates a transport capacity in excess of sediment supply ($Q_c > Q_{sin}$), whereas an alluvial streambed indicates either a balance ($Q_c = Q_{sin}$) or an excess of sediment supply ($Q_c < Q_{sin}$) (Howard and Kerby, 1983; Gilbert, 1877). Montgomery *et al.*'s (1996)

finding in their critical slope model that bedrock channels occur on steeper slope than alluvial channels of comparable drainage area implies an excess transport capacity that should render bedrock channels insensitive to changes in sediment supply or discharge. However, an incised channel network with outcrop bedrock features could respond differently to changes in sediment supply or discharge due to the presence of rigid boundaries and the fact that it may not lie on a steep slope. For instance, the incised bedrock-controlled Sabie River in Kruger National Park, South Africa shows varying levels of sediment storage in its different channel types (Cheshire, 1994; Van Niekerk and Heritage, 1993).

Bedrock-controlled reach represents the intermediate position between alluvial channels, in which stored sediment lines the entire channel, and steep bedrock channels, in which lack of sediment input or high transport capacity precludes sediment storage (Ashley *et al.*, 1988). Alluvial and bedrock channels can therefore be considered as end points of a continuum (Brakenridge, 1985) of varying sediment supply in relation to transport capacity (Ashley *et al.*, 1988). Thus sediment supply and transport capacity are important factors in modelling sediment transport and geomorphic response.

Sediment supply to natural channels originates from erosion processes operating in the surrounding catchments and is delivered to the channels by transport agents, which include runoff, wind and mass movements. Some of the land use activities that normally avail sediment load for transport by these agents include agriculture, mining, road and pipeline construction, dam construction, timber harvesting or deforestation, urbanisation, building activities, use of fire, ploughing, overgrazing, etc. These activities affect the spatial and temporal availability of sediment. The changes in runoff and sediment production occasioned by these activities in turn affects the river channel and induce change. The changes in sediment supply can alter the dynamic equilibrium between sediment transport and water discharge, thus initiating changes in the channel form and altering the physical and biological characteristics of the system (Hall and Krygier, 1967; Heede, 1975; Park, 1977; Wevers and Warren, 1986).

It has emerged clearly that in river reaches with physical barriers, the physical controls such as bedrock outcrops, hydrology or hydraulics, sediment availability and/or sediment supply, and sediment characteristics such as size are very important parameters with regard to sediment accumulation and transport capacity of the channel. These factors shape the morphology of the channel by directly or indirectly influencing sediment storage changes in the channel.

2.5 The effect of non-alluvial and alluvial features on sediment dynamics

Fluvial sediment deposition in bedrock-controlled channels is controlled by the geometry and trap efficiency of non-alluvial and alluvial features, their role in dissipating stream energy, and their effect on local water surface slope and flow patterns (Swanson *et al.*, 1976; Lisle, 1986; O'Connor *et al.*, 1986; Carling, 1989). Sediment transport and storage may not therefore be entirely treated as simple functions of flow hydraulics and mobile channel boundary. The constraining influence of non-alluvial and alluvial features must be considered.

The presence of non-alluvial and alluvial features in bedrock-controlled channels creates three-dimensional oscillatory responses. These act like secondary currents (localised flow perturbations due to local changes in form) and cause the initial conditions of morphology to change faster in response to processes of sediment transport (erosion and deposition). This leads to transient behaviour in which feedback occurs between system state (form) variables and process form variables (Hey, 1979). It can thus be hypothesised that it is neither processes in bedrock-controlled channels, which entirely control channel form, nor form which entirely controls process, rather, form and process evolve together as feedback mechanisms.

Richards (1987) gives an example of the upstream and downstream feedback which causes oscillatory response at a river section after a sudden fall in base level. This arises when the developing morphology (bed slope and cross-section geometry) affects the sediment transport capacity, resulting in temporal fluctuations in the balance between

local transport capacity and sediment supply from upstream. This temporal imbalance between the upstream sediment supply and the transporting capacity of the flow influences temporal changes in channel morphology.

Rivers are usually in a state of continual change in view of the spatially and temporally distributed feedback resulting from the interaction of morphology, sedimentology, flow hydraulics and sediment transport processes. According to Lane *et al.* (1995) fluvial systems are in a state of continual change, as process events of varying magnitude continually act on an ever-changing morphology, whose shape itself influences the pattern of the formative processes.

Since bed load consists of relatively coarse particles transported near or on the bottom of the stream the average velocities of these particles are much less than that of the stream. This combined with the fact that the backing up of flow by non-alluvial and alluvial features cause local reduction in flow velocity and bed shear stress, therefore promote deposition.

2.5.1 Non-alluvial features

The non-alluvial features in bedrock-controlled natural fluvial systems include the rigid bed and banks of the channel, boulders, organic debris and bedrock outcrops of different shapes and sizes. These features are generally common in the upstream steep sections of bedrock-controlled channels. In particular, bedrock outcrops, boulders and large organic debris, commonly control the morphology of steep mountain streams (Keller and Swanson, 1979). This is because they induce sediment deposition. In showing that the percentage channel area of stored sediment (i.e. areas of sediment stored/total channel area) in areas with organic debris is higher than those channels that have no organic debris, Keller and Tally (1979) vividly illustrated the effect of non-alluvial features.

Bedrock outcrops can also be found in less steep downstream sections of the channel particularly if incision of the channel has occurred. Incision results from base level

lowering, uplift, or climatically induced changes in water and sediment fluxes (Baker, 1984). For instance the Sabie River, South Africa, with a bed consisting predominantly of unconsolidated coarse sand and fine gravel, is an incised channel heavily influenced by bedrock features. These bedrock features constitute flow boundaries and roughness elements that are not of alluvial origin. In the Sabie River, these resistant bedrock outcrops lead to local downstream steepening of the river and upstream decrease in gradient resulting in localised sediment accumulation (Van Niekerk and Heritage, 1993).

The effect of non-alluvial bedrock outcrop features on hydraulics and sediment transport is comparable to that of small hydraulic structures built across the channel. Such hydraulic structures include bridge piers, cofferdams, weirs, some types of intakes, check dams, gabions, etc. These structures may not create substantial changes in water and/or bed levels directly, but cause secondary currents and uneven velocity distribution and hence generate local scour or deposition (Novak and Cabelka, 1981). This is because, like the non-alluvial bedrock outcrops, they cause obstruction to the flow, and there must therefore be mutual interference between them and the flow. Non-alluvial boundaries and obstructions, thus, introduce complex flow structures (Furbish, 1993). The resulting flow is three-dimensional comprising secondary circulation, flow separation, and the birth and decay of vorticity around obstacles and along irregular boundaries (Matthes, 1947).

The complex flow structures contributed by the non-alluvial boundaries and obstructions invalidate the basic assumption of channel self-formation (Lisle, 1987) characteristic of alluvial channels as noted in section 2.2. In which case the response of these channels to flow conditions is different from that of channels composed basically of alluvial roughness elements (bars and bed forms). Furthermore, the arrangement of fluvial sediment accumulations along the channel is then predisposed to reflect the location and spacing of non-alluvial elements, rather than some scaling of the flow and sediment properties of the channel (Rice and Church, 1996). According to the latter authors, where immobile boulders and bedrock obstructions are the primary non-alluvial elements, their distribution along the channel and the resulting location of stored sediments will tend to be irregular. Thus, non-alluvial storage controls have a significant impact on the pattern

of variation in streambed sediments. This consequently causes the channel stability and morphology to strongly depend on the spatial arrangement and temporal dynamics of non-alluvial features (Hogan, 1989) with subsequent dominance on sediment storage (Rice and Church, 1996).

The shapes, sizes, numbers and locations are also important because the bedrock outcrop features found in natural bedrock channels vary widely in these respects and any combination of the variations influence flow hydraulics and consequently sediment transport and deposition differently. The numbers and locations are particularly important with regard to defining the spatial distribution network of the bedrock features. The size, shape and the distribution pattern of the bedrock in conjunction with the magnitude of flow is important in influencing the scale of local turbulence. The magnitude of the scour or deposition is therefore likely to be influenced by the shape(s), location, number and size(s) of the geomorphic feature(s) since these factors directly influence the area and consequently the velocity distribution. For instance, Babaeyan-Koopaei and Valentine (1997) attribute the scour observed at the end of the bridge abutment that obstructs flow in a laboratory flume to: contracted flow and subsequent increased velocity; and forced flow returning to the opening in the vicinity of the abutment. However, if the influence of the obstruction does not over-concentrate the flow, then the magnitude of the turbulent eddies and vortices generated by the converging flow at the obstruction (i.e. abutment in this case) is diminished, reducing the erosive velocities and turbulence which cause local scour. Therefore, the magnitude of the influence of the obstruction on flow and erosion or deposition is controlled by factors such as the obstruction size, shape, number and distribution/ location.

The influence of bedrock features on flow involves intense energy dissipation though this is a function of the flow magnitude, the number, sizes, shapes and spacing / location of the bedrock controls. The structures cause energy dissipation as eddies and render transport rate unstable in time and space even under constant flow conditions, resulting in local sediment accumulation, increases in form resistance and reduction in available energy for transport.

The shapes, numbers, sizes and the location of non-alluvial features contribute to the classification of the different geomorphic types.

2.5.2 Alluvial features

In bedrock-controlled channels, sediment is dominantly deposited in the form of discrete geomorphic features (bars). The bars, just like non-alluvial features, contribute to the classification of the river into different geomorphic types. The bars also contribute to the process-response feedback and complicate the flow hydraulics. It is therefore important to understand the bar dynamics, as it is an important component of the sediment transport and storage dynamics in bedrock-controlled rivers.

Bathurst (1978) in studying flow resistance of large-scale roughness established that large-scale roughness elements (e.g. boulders) individually affect flow and sediment transport in complex ways that depend on their shape, spacing, and location. According to the study the local flow is non-uniform with zones of separation, acceleration, and deceleration around the roughness elements, but on the average along a reach the flow is uniform. Zones of separation, acceleration, and deceleration contribute to non-uniform sediment distribution in the channel and hence influence macro bed form (bar) deposition. The sediment accumulation associated with bar deposition results if there is reduced local sediment transport capacity. The shapes and spacing of some bed forms seem to create maximum resistance to flow (Davies, 1980). The size of bed forms, however, is related to sediment properties and flow conditions (Lisle, 1982).

Bars generally result from localised deposition of bed material. The most common types include point bar, alternate bar, middle bar and tributary bar (Simons and Simons, 1987). The point bar forms on the inside of the bend. Alternate bars are a precursor of meandering in many systems. Middle bars become islands where the river is exceptionally wide. Tributary bars are formed where steep tributaries carrying heavy sediment loads deposit material in the mainstream at the confluence. According to the

latter authors, the bar material is of sufficient size and of sufficient quantity that it cannot be immediately transported.

Scour and deposition around large bedrock features in or along channels can cause bars to form where they would not otherwise have formed (Kinoshita and Miwa, 1974; Florsheim, 1985) or at least fix the positions of bars and pools (O'Connor *et al.*, 1986; Lisle, 1986). This is because these resistant non-alluvial boundaries inhibit lateral migration and can control the position of macro bed forms (Lisle, 1987).

Channels in which fine sand is the dominating sediment in transport have conventionally been associated with the formation of small scale wavy like bed forms e.g. ripples, dunes, anti-dunes and flat beds and have been taken to rarely deposit bars. This is because most of the fine sediments remain in suspension or are continuously exchanged between the bed and the flow. The bed forms are essentially two-dimensional vertical deformations of the channel bed. However, with the influence of non-alluvial features (e.g. boulders), sand bed channels have been shown to form diverse morphological features e.g. mid-channel bars, braid bars, lateral bars, point bars, riffles, pools, etc. (Van Niekerk and Heritage, 1993). The presence of non-alluvial features causes lateral variation in flow direction or properties and therefore allows the bed configuration to vary laterally, giving rise to characteristic plan form shapes.

The large-scale forms affect particle entrainment, transport paths, and frictional losses and constitute some of the basic features of channel morphology (Lisle, 1987). If the features formed are alternate bars, the channel can most efficiently transport sediment by creating zones of concentrated stream power. This is because in alternate bars, the bed load converges into zones of increasing unit stream power (pools) and diverges over zones of decreasing unit stream power (bars). Bed load can thereby be transported at substantial rates in quasi-equilibrium with channel morphology (Lisle, 1987). Another study by Parker and Peterson (1980) on gravel bed streams showed the influence of bars as roughness elements to be greatest at low flow when ponding of water in pools behind bar crests produces flows that are deeper and slower than would otherwise exist

(Bathurst, 1981). Because of their size and mobility, bars deform slowly and are usually adjusted to long term trends in sediment load and flow conditions (Lisle, 1982). However, according to Lisle (1987), the resulting strong influence of irregular, non-alluvial boundaries and a weakness in the tendency to form bars in some mountain streams, regularly repeating bar-pool sequences may not be present or easily delineated. This explains the fact that the bars formed are diverse and may not be regularly alternating to define regularly repeating bar-pool sequences. For instance, Grant (1986) and Sullivan (1986) define channel unit types, e.g., pools, rapids, and cascades that are not necessarily tied to freely formed bar-pool sequences, but have quantifiable, hydraulic and morphologic domains.

The formation of bars and other geomorphic features in channels contribute to form roughness, which according to Richards (1987) is quantitatively significant relative to the grain roughness and complicates theoretical estimation of bed load transport from hydraulic data. This is because the transport is driven by that part of the bed shear stress balanced by the grain drag, and the total bed shear stress therefore has to be partitioned. However, according to extremal hypotheses channel forms minimise rates of potential energy loss, or maximise frictional resistance or bed shear stress; that is, that the morphology of a river dissipates energy sufficiently. The efficient minimal rates of energy dissipation regulate sediment transport, deposition and scouring processes around these features and lead to the formation of distinct geomorphic features. Braided rivers, for example, have been noted to be efficient energy dissipaters because of the subdivision of the flow and its frequent diversion around bars. Braiding refers to branching and rejoining around alluvial islands or bars. Thus mid-channel bars produce short braided reaches. The spatial redistribution of kinetic energy associated with braiding leads to a downstream reduction in the vertical energy gradient and therefore provides a zone for sediment accumulation and subsequent bar growth (Ashworth, 1996). Another example is pool-riffle sequences, which generate localised energy dissipation while transporting the sediment, resulting in their self-stabilisation.

The review shows clearly that bar dynamics is an integral component of sediment dynamics in bedrock-controlled rivers. They provide the morphological diversity of bedrock-controlled river systems and contribute towards their classification into different channel types or morphology classes or types. The bars have also been shown to contribute to complexity of flow hydraulics and therefore complicate sediment dynamics in bedrock-controlled rivers. While most of the studies quoted in this review have observed large scale roughness herein associated with bars in complex river morphologies (bedrock-controlled or alluvial braided), a number of studies in the second half of twentieth century tried to reproduce bar dynamics in the laboratory flumes. Such studies include those of Schmidt *et al.* (1993), Warburton and Davies (1994), Ashmore (1982) among others. Nicolson (1999) modelled the dynamics of bar transport and storage in bedrock-controlled rivers qualitatively. These attempts highlight the recognition of the role played by bar dynamics in river hydraulics.

The current study will not model the bar dynamics but acknowledges it as part of the contribution to complexity in flow hydraulics and morphology types in bedrock-controlled rivers. This thesis views the complexity in local flow hydraulics and local morphological diversity as important in determining the spatial and temporal scales of modelling. Furthermore, the flow and form complexities are indicators that more detailed boundary shear stress theories of modelling sediment transport are difficult to verify because of the highly localised changes that complicate monitoring. Less detailed studies using average sediment transport and storage potentials of sediment storage units with similar sediment transport and storage characteristics may therefore be preferable. Once the sediment transport and storage characteristics of different morphology classes or channel types are known, then methods that simply account for sediment storage changes in such channels (e.g. sediment budgeting) with different flow events may be sufficient for modelling the sediment dynamics of such river systems.

2.6 The effect of constriction and expansion on sediment dynamics and geomorphic response

Bedrock rivers often display relatively abrupt flow expansions and constrictions, in contrast to the more uniform or gradually varying width characteristics of alluvial streams (Baker, 1984). This behaviour of bedrock rivers has important sedimentologic consequences, as recognised by Krumbein (1942) in his study of flood deposits at Arroyo Seco, near Los Angeles. The study found that irregular flow boundaries and high flow velocities resulted in very coarse bed material being thrown into suspension. This suspended material was found to be deposited in the backwater zones for flood flows upstream of constrictions, while the high velocity flows through constrictions induced scour and extremely high flow competence. Abrupt flow expansions may occur at the mouths of tributaries, especially where a deep tributary canyon enters the trunk canyon at a high angle. Very resistant rock units may also form local, narrow gorge reaches on trunk canyons that end at abrupt expansions. However, in the context of the current study, the location of the non-alluvial feature will be considered to constitute an abrupt constriction and therefore result in an abrupt expansion to the flow downstream.

The current study will not look at the details of sediment dynamics due to abrupt constriction and expansion, but acknowledges it as an important consideration in modelling sediment dynamics in bedrock-controlled rivers. It contributes to part of the complexity in flow hydraulics and associated sediment transport and storage.

If flood flows become supercritical or critical in constricted reaches, the subsequent transition to an abrupt expansion can induce a hydraulic jump. If this happens, then the kinetic energy in the constricted, high-velocity flow is transformed to potential energy in the deep, low-velocity flow downstream from the jump. This transition involves an abrupt loss of mechanical energy through the generation of intense turbulence within the jump. The transition point will be the site either of erosion into bed material or non-deposition of the coarse bed load in transport (Baker, 1984) with a possibility of deposition immediately downstream in the expansion. For example, Jopling and

Richardson (1966) illustrated in their experimental study, accumulation of Fan-shaped deposits immediately downstream.

Florsheim and Keller (1987), studied the relationship between channel morphology, energy slope, unit stream power distribution, and sediment storage and routing over a spectrum of low to high magnitude discharges in a small, 2.14 km², bedrock controlled drainage basin by modelling flow events utilising the HEC-2 step backwater computer programme. The findings of this study suggest that:

- (1) energy gradients at all flows are steep through bedrock constrictions, indicating a high rate of energy loss;
- (2) energy gradients are relatively gentle upstream of constrictions in areas affected by backwater flow and downstream of constrictions where channel expansions occur;
- (3) the length of channel affected by backwater flow upstream of constrictions is less at low discharge than at high discharge;
- (4) peaks in unit stream power occur in bedrock constrictions while minima occur in areas affected by backwater flow and in channel expansions;
- (5) the spatial distribution of sediment deposition during a low magnitude flow is greatly influenced by bedrock controlled channel geometry, and there is an inverse relation between unit stream power and volume of sediment stored in a particular reach of channel (sediment is deposited both upstream and downstream of bedrock constrictions, while within constrictions, little sediment is deposited); and
- (6) although the distribution of unit stream power is often complex, modelling explains the gross location of sediment deposits and, thus, routing.

The quoted study supports the hypothesis of non-uniform distribution of sediment in a bedrock-controlled channel and makes it clear that sediment gets deposited upstream of constrictions where backwater effects are present, and downstream of constrictions where channel expansions occur. Thus constrictions and expansions have remarkable influence on the morphology, hydraulics and bed load transport capacity.

Constriction and expansion in rigid boundary channels is viewed from the perspective of that contributed by the bedrock outcrop features. This is because the rigid bed and banks

do not allow flow to contract and expand but bedrock outcrop features contribute to fluvial hydraulics of convergent and divergent flow.

2.7 Geomorphological and hydraulic characteristics of bedrock-controlled rivers

Most bedrock-controlled channels have alternating reaches of exposed bedrock and sediment cover. This means that bedrock-controlled channels have their gross morphology constrained by the bedrock. The characteristics of bedrock-controlled channels either tend towards those of a bedrock channel or those of an alluvial channel depending on the degree of sedimentation. It is therefore important to have a general understanding of the characteristics of bedrock channels that distinguish them from alluvial channels.

Miller and Cluer (1998) provide a fairly good representation of the behaviour of bedrock channels particularly their influence on flow as italicized in the subsequent statements. *Bedrock channels generally have higher gradients and frequently are incised as a result of regional uplifts or base-level lowering. Irregular boundaries are common and may include abrupt constrictions and expansions. Flow patterns may be complex and flow fields are often difficult to measure directly, especially at high flows when conditions are hazardous and accessibility is limited. Even at low stages, greater velocities than in alluvial channels are shown. Flow is never steady and uniform. Critical flow is extremely common, although usually confined to part of the channel, and supercritical flow is not uncommon, although spatially restricted. The irregular and discontinuous shape of the water surface and velocity field in the presence of transcritical flow poses a challenge for modelling and therefore any consideration of model applications in bedrock channels need to address this issue.* However, not all model applications require comparable levels of detail in simulating flow patterns. The precision of treating the flow is variable and depends on the level of detail desired of the results as well as what is practically and theoretically possible. Thus the modelling scale of resolution (level of detail) other than depending on the purpose of the model results (section 3.7) also

depends on the extent to which the flow behaviour can be accurately represented or reproduced.

The above characteristics clearly indicate that alluvial and bedrock reaches of bedrock-controlled rivers are geomorphologically and hydraulically different. They are geomorphologically different because individual channel reaches are constituted of alluvial matter or bedrock matter or both and have diverse slopes. The geomorphology is made much more complex by the orientations or forms of the sediment storage and/or storage units as well as their sporadic locations of deposition. The complex geomorphology results in complex hydraulics making the bedrock-controlled rivers hydraulically diverse. The differences in local velocities and water surface slopes are indications of the hydraulic diversity. This means that any model built to predict sediment movement and storage in bedrock-controlled rivers must be built at a spatial scale that recognizes the geomorphological diversity in such river systems. The coarsest resolution at which such a model can be built is that which simply distinguishes the alluvial reaches from the bedrock reaches and recognizes the associated hydraulic differences within the different reaches. However, if a detailed resolution model is required then the model must be built at a finer spatial resolution provided the differences in geomorphology and hydraulics are recognizable.

The geomorphology of the bedrock-controlled Sabie River, in South Africa has been explained in the ensuing section 2.8 and subsections 2.8.1 and 2.8.2 to show the complexity of bedrock-controlled rivers in terms of flow hydraulics and bedrock-sediment association. The geomorphological diversity of the Sabie River has been used to show the need to model sediment movement and storage in bedrock-controlled rivers differently from that of alluvial reaches.

2.8 The geomorphology of the bedrock-controlled Sabie River

The geomorphology of the Sabie River, which is a good example of a bedrock-controlled river in South Africa for which a new sediment routing concept has been developed in

this thesis, has been explained. The complexity of the Sabie River in terms of its geomorphology, sediment transport and storage characteristics, and flow hydraulics needs to be thoroughly understood in order to develop an appropriate method that can route sediment efficiently through this complex river system. The Sabie River rises beyond the western boundary of Kruger National Park (KNP) and flows eastwards towards Mozambique. It drains catchments that are subjected to agriculture, industry, forestry, subsistence farming and urban settlement. It drains 6000 km² of the Mpumalanga province in the north east of South Africa (Fig. 2.1).

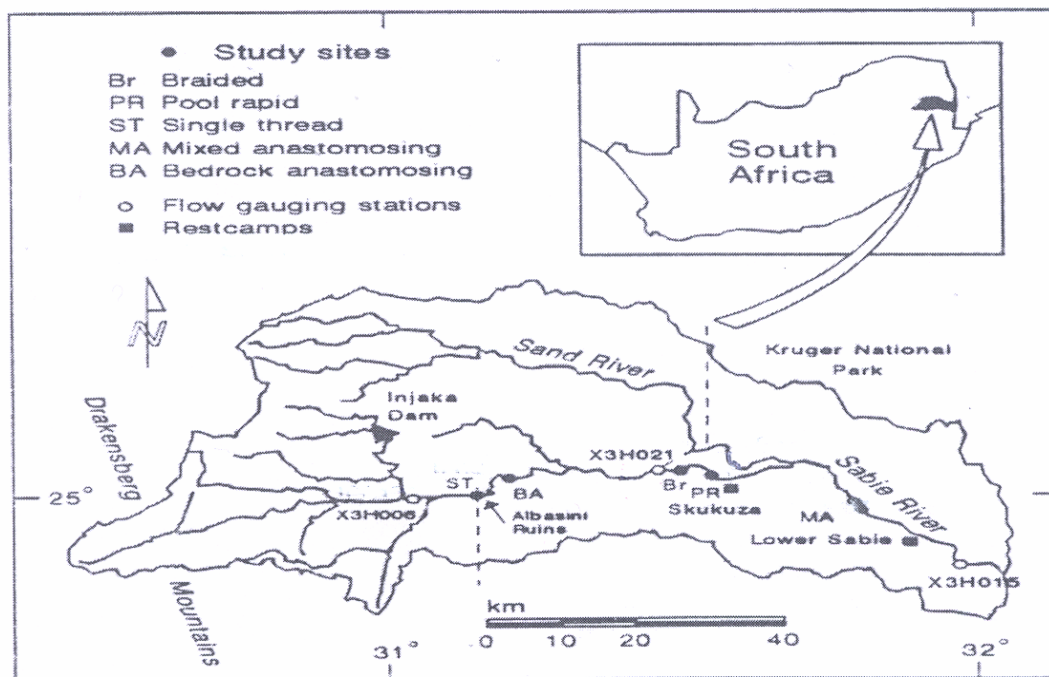


Figure 2.1: Sabie River catchment with some of the study sites of Birkhead *et al.* (2000) shown along the river

The river is confined to a valley cut into the bedrock, and active channel evolution and sedimentation are restricted within this zone, which is termed the macro-channel (van Niekerk *et al.*, 1999). The morphology of the Sabie River is therefore controlled by the underlying geological structure and bedrock *lithologies*, *although alluvial characteristics may occur within the macro-channel* (van Niekerk *et al.*, 1999). There is a large degree of

bedrock control on the bed and banks of the active and macro-channels. Bedrock outcrops in the bed and banks lead to local steepening of the river and an upstream decrease in water surface gradient resulting in localized sediment accumulation.

The Sabie River is a geomorphologically diverse river system displaying both alluvial and bedrock features. Within the Kruger National Park (KNP) the Sabie River forms active channels within a larger macro-channel, exhibiting characteristics of both alluvial and bedrock-controlled rivers. It displays rapid changes in channel types as distribution of sediment over bedrock changes. Five principal channel types have been identified through aerial photographic analysis and field survey: bedrock anastomosing, mixed anastomosing, pool-rapid, braided and alluvial single thread (van Niekerk *et al.*, 1995). The categorization was based on the geological influence and the degree of accumulated sediment (characteristic morphological components) within the channel. In bedrock anastomosing and pool-rapid channel types, bedrock features are common, while in mixed anastomosing, braided and alluvial single thread, bedrock features become progressively less important as alluvium builds up in the macro-channel (Heritage *et al.*, 1999).

Bedrock outcrops projecting above the water surface especially during low flows characterize most sections of the Sabie River. These bedrock structures act as control points and thus create backwater zones upstream. These zones are characterized by sediment accumulations resulting from reduced shear stress. The sediment originates from outside of the Kruger National Park in the former homelands with a concentration of impoverished landscape with poor vegetation cover due to overgrazing and poor farming practices (van Niekerk and Heritage, 1994). Introduction of this sediment into the river system is episodic, associated with summer rainfall events (Heritage *et al.*, 1999).

2.8.1 Bedrock-sediment association in bedrock-controlled Sabie River

The scope of bedrock-sediment association for the different channel types on the Sabie River is shown in Table 2.1. This Table gives an approximate indication of the percentages of alluvial and bedrock structures found in the macro channels and active channels of the different channel types on the Sabie River. The Table clearly illustrates the dominance of alluvial structures in braided and single thread channel types. This is clearly illustrated by comparing the percentages of in-channel features of lateral bars and alluvial pools in braided and single thread channel types to those of the other channel types.

The dominance of either alluvial or bedrock structures in the other channel types cannot be clearly deciphered from the in-channel features on the Sabie River as they in general display both alluvial and bedrock sections. The bedrock influence in these channel types needs to be underscored as it contributes to the sediment accumulations within them. The significant percentages of mixed pool in bedrock anastomosing, pool-rapid and mixed anastomosing channel types is a clear indication of the effect of bedrock structures in these channel types. The significance of bedrock structures within these latter channel types can be observed from the significant percentages of bedrock core bar as an interfluvial feature. Bedrock core bar is an accumulation of fine alluvium over sand on bedrock outcrops between distributary channels. Significant percentage of bedrock core bar is therefore an indication of the dominance of bedrock outcrops.

Single thread channel types (Fig. 2.2) have developed in the alluvial sections of the Sabie River. Single thread channel types are fully alluvial. They are characterized by a single channel flowing between lateral bars and/or terrace features and have a range of sinuosities and associated alluvial single thread morphologies (Broadhurst *et al.*, 1997). However, this channel type is not as common as the other channel types in the Sabie River. This is because the Sabie River is dominantly bedrock-controlled and sections that are completely alluvial are rare. Such sections mostly occur where sediment deposition has largely obscured the bedrock influence.

Table 2.1: Morphological unit association by channel type for the Sabie River in the Kruger National Park. Figures represent in-channel and interfluvial percentage areas, smaller features are described qualitatively based on field observation (Source: Heritage *et al.*, 1999)

Morphological unit	Braided	Bedrock anastomosing	Pool-rapid	Single thread	Mixed anastomosing
<i>In-channel features</i>					
Braid bar	13.2	2.4	5.0	1.4	1.8
Lee bar	0.2	-	-	-	0.3
Lateral bar	23.6	1.1	12.2	30.5	2.1
Rapid	1.7	5.0	5.1	-	2.1
Isolated rock	0.3	1.4	1.2	0.1	2.1
Alluvial pool	49.6	14.8	31.9	68.0	11.3
Mixed pool	2.8	20.1	19.9	-	17.7
Bedrock pool	-	6.2	1.4	-	1.2
Other water	3.0	11.0	10.0	-	12.4
Rip channel	rare	absent	rare	rare	rare
Cataract	rare	absent	rare	absent	absent
Waterfall	rare	absent	rare	absent	absent
Armour area	absent	rare	rare	absent	rare
Boulder bed	absent	rare	rare	absent	rare
Dead zone	rare	rare	rare	rare	rare
<i>Interfluvial features</i>					
Alluvial backwater	0.02	0.2	0.1	-	0.2
Bedrock backwater	-	0.6	0.1	-	0.2
Bedrock core bar	5.7	38.0	13.3	-	48.8
Terrestrial rock area	-	15.5	2.5	-	3.8
Bedrock pavement	-	1.4	0.2	-	0.2
Island	-	7.8	0.4	-	18.3
Macro-channel bank	69.5	24.9	44.7	57.9	22.8
Macro-channel lateral bar	30.3	49.7	52.0	42.1	54.6
Levee	rare	absent	rare	rare	rare
Terrace	rare	absent	absent	common	absent
Riffle	rare	absent	absent	rare	absent

Key: absent = not encountered; rare = seen at less than one in five cross-sections; common = seen at most cross-sections



Figure 2.2: Typical single thread channel type (Source: Broadhurst *et al.*, 1997)

Braided channel types (Fig. 2.3) are alluvial systems that exhibit channel splitting and rejoining over a distance of a few channel widths (van Niekerk *et al.*, 1995; Heritage *et al.*, 1999). The divergence of the channels occurs around sedimentary bars. Braiding in the Sabie River usually occurs upstream of bedrock controls where backwater effects reduce the transport capacity of the river (van Niekerk and Heritage, 1993). The reduction in stream competence leads to deposition.

The degree of braiding in the Sabie River is low and appears restricted to the deposition of mid-channel bars (accumulations of unconsolidated sediment in the centre of the channel) and lateral bars (accumulations of unconsolidated sediment at the sides of the channel) within the active channel (Heritage *et al.*, 1999). The alluvial braided channel types have no bedrock influence due to the deep alluvial deposits (Heritage *et al.*, 1997).



Figure 2.3: Typical braided channel type (Source: Broadhurst *et al.*, 1997)

The pool-rapid channel type (Fig. 2.4) displays both bedrock and alluvial features to varying degrees. The pool-rapid channel type reaches are typically composed of alternating pools and rapids with closely packed, often partly continuous bedrock outcrop, covering between 25%-75% of the reach area (Cheshire, 1994). The rapids are mostly free of sediments while the pool areas are more variable, ranging from sediment-free bedrock areas to bedrock-lined pools incorporating a variety of bar types. Sediment accumulates in the pools upstream of the rapids particularly as mid-channel bars, lateral deposits and braid bars (Heritage *et al.*, 1999; van Niekerk and Heritage, 1993; Cheshire, 1994).

Pool-rapid reaches are like a series of sediment trapping reservoirs. They consist of large pools, which dam up behind bedrock outcrops in the river. Bedrock outcrops control the flow in a pool-rapid channel type. The pools are deep and have slow moving water, while

the rapids at the end of each pool are very steep with shallow, supercritical flow. At low flows the pool sections have very mild water surface slopes and are low energy environments. At higher flows the rapids drown out and the water surface slope is more uniform throughout the entire pool-rapid reach.



Figure 2.4: Typical pool rapid channel type (Source: Broadhurst *et al.*, 1997)

Anastomosis refers to interconnected channel systems whether in alluvial streams or in bedrock streams. Anastomosing channels form a network of anabranching channels. Mixed anastomosing channel type (Fig. 2.5) consists of multiple bedrock, mixed and alluvial distributary channels that divide and rejoin over a distance much greater than the distributary width (Heritage *et al.*, 1999; Birkhead *et al.*, 2000). A small percentage of the active distributary channels are filled with alluvial material in the form of lateral bars attached to the banks, mid-channel bars in the centre of the channel, lee bars behind obstructions to the flow and mixed and alluvial pools (Table 2.1) (Heritage *et al.*, 1999). Laterally extensive deposits of sediment have been observed to occur immediately downstream of the rock controls where the river channels converge due to the reduction in gradient, and hence, transport capacity of the river in the area downstream of the rock

controls (van Niekerk and Heritage, 1993). The individual channels may contain pool-rapid sequences or alluvial forms.

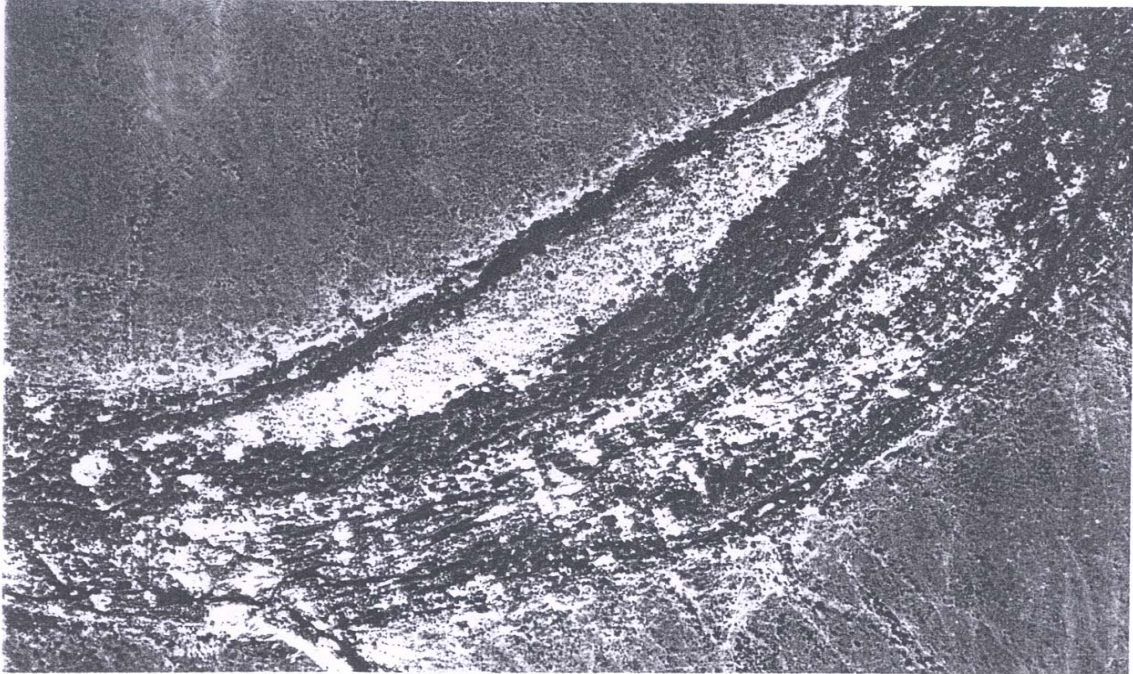


Figure 2.5: Typical mixed anastomosing channel type (Source: Heritage *et al.*, 1997)

Bedrock anastomosing channel types (Fig. 2.6) consist of steep bedrock distributaries making them high energy systems that display very few alluvial features, with sediment accumulation being restricted to lateral deposits and alluvium in pools (Heritage *et al.*, 1999). Elevated bedrock areas are common and may exist as exposed bedrock pavements (Heritage *et al.*, 1999). Observations following elevated flows and consideration of channel hydraulics suggest that deposition on exposed bedrock occurs during the falling limb of flood hydrographs, leading to the development of bedrock core bars (van Niekerk *et al.*, 1999). Sediment transported through the anastomosing sections is deposited in the lower energy areas downstream of the major bedrock controls (van Niekerk *et al.*, 1999) as lee bar deposits (Broadhurst *et al.*, 1997).



Figure 2.6: Typical bedrock anastomosing channel type (Source: Birkhead *et al.*, 2000)

Bedrock anastomosing sections are associated with outcrops of more resistant rocks. These channel type reaches are typically composed of continuous bedrock pavement with smooth to irregular flat lying surface, covering up to 75% of the reach area (Cheshire, 1994) and the resistance is therefore low due to smooth surface of the pavement.

Bedrock anastomosing channels have a greater capacity for transporting most of the sediment sizes and quantities supplied from the catchment than other channel types found on the river for all flows (van Niekerk *et al.*, 1999; Heritage *et al.*, 1999). This can be attributed to their high energy slopes (Table 2.2) resulting from flow over their steep gradients. The low resistance associated with the smooth surface of the pavement also contributes to high sediment transport capacity. High sediment transport capacity result in low alluviation. However, rapid establishment of vegetation leads to a positive feedback whereby the bedrock core bars are stabilized and deposition is enhanced through the reduction of energy of flow and trapping by vegetation (van Niekerk *et al.*, 1999). The impact of vegetation is projected to drive these systems towards a more alluvial state in the long term. However, that impact may not be sustainable as major floods will deplete

these systems of sediment deposits and vegetation and make them revert to their bedrock anastomosing status. This situation was observed in the Sabie River after the 1996 and 2000 floods. The catastrophic floods stripped the river of most of the sediments and exposed much of the bedrock. Thus bedrock and alluvial states of anastomosing reaches are not permanent but keep on switching in response to flow and sediment supply.

In summary single thread and braided channels are alluvial, pool-rapid channels are bedrock or mixed alluvial bedrock, and the anastomosing channel types range from bedrock, through mixed to alluvial (van Niekerk *et al.*, 1999).

The bedrock features that are deeply embedded in deep alluvial deposits (sedimentary features such as lateral bars and braid bars) in alluvial channel type reaches are typically single boulder bedrock-outcrops. These reaches have low gradient (Cheshire, 1994). Lack of significant bedrock projections implies that these channel reaches are likely to have low resistance, which may be associated with high sediment transport. However, due to low gradient and vegetation colonization the sediment transport may not be higher than that of the bedrock dominated channel types found within steep gradients.

Table 2.2: Sabie River channel/cell regional and estimated energy slopes (Source : Birkhead et al., 2000)

Cell No.	Channel type					Regional slope (1:50 000)	Energy slopes				
	ST	BR	PR	MA	BA		ST	BR	PR	MA	BA
1	x					0.00302	0.00127				
2		x				0.00268		0.00138			
3			x			0.00233			0.00217		
4		x				0.00233		0.00138			
5			x			0.00233			0.00216		
6		x				0.00233		0.00138			
7					x	0.00233					0.00644
8		x				0.00233		0.00137			
9					x	0.00233					0.00637
10			x			0.00233			0.00215		
11		x				0.00233		0.00137			
12					x	0.00571					0.00635
13			x			0.00394			0.00214		
14		x				0.00331		0.00136			
15			x			0.00331			0.00213		
16					x	0.00331					0.00623
17			x			0.00331			0.00212		
18					x	0.00361					0.00609
19			x			0.00364			0.00210		
20					x	0.00364					0.00566
21	x					0.00364	0.00121				
22					x	0.00342					0.00566
23			x			0.00305			0.00201		
24		x				0.00305		0.00132			
25			x			0.00305			0.00200		
26					x	0.00317					0.00551
27			x			0.00198			0.00197		
28		x				0.00167		0.00130			
29			x			0.00178			0.00195		
30				x		0.00225				0.00331	
31		x				0.00225		0.00129			
32				x		0.00225				0.00329	
33			x			0.00255			0.00192		
34				x		0.00284				0.00269	
35		x				0.00265		0.00116			
36				x		0.00200				0.00264	
37		x				0.00160		0.00115			
38			x			0.00179			0.00149		
39				x		0.00265				0.00261	
40					x	0.00408					0.00314
Average							0.001240	0.001315	0.002024	0.002908	0.005717

Key: x - Cell channel type; BR - Braided; BA - Bedrock anastomosing; PR - Pool-rapid; ST - Single thread; MA - Mixed anastomosing.

2.8.2 Sediment transport potential hierarchy for the different channel types

The differences in regional gradients, differences in alluvial and bedrock structures as well as the vegetation growing either on the sediment deposits or bedrock within different channel types on the Sabie River contribute to variations in the energy slopes of flows through the bedrock-controlled river system. The unit stream power ($\gamma Q_w S_f / b$: where γ is the specific weight; Q_w is the discharge; b is the channel width and S_f is the energy gradient) which is the driving mechanism in sediment transport is dependent on energy slope. Thus the sediment transport (scour) potential and consequently the sediment storage in each channel type are related to the energy slopes for the given discharges.

Birkhead *et al.* (2000) compared regional slopes and high (flood) water surface slopes from representative cross-sections for all the channel types on the Sabie River. The study found the regional slopes to approximate the water surface slopes within reasonable levels of accuracy. Since it was difficult to measure water levels in all the channel types in the entire length of the Sabie River flowing through Kruger National Park during flood flows, Birkhead *et al.* (2000) estimated the high flow water surface slopes from the regional slopes. Assuming the longitudinal change in velocity head to be negligible the energy slope was considered to be equal to the water surface slope. Exceptions were the high gradient bedrock anastomosing channel type cells, where Birkhead *et al.* (2000) found the low flow slopes to provide better estimates of the flood profiles than the spatially averaged regional slopes from the 1:50 000 topographical maps.

The method used by Birkhead *et al.* (2000) has been adopted in this study as appropriate for estimating the energy slopes for the different cell/channel types along the length of the Sabie River (Table 2.2). It is important to note that the length of the Sabie River flowing through Kruger National Park has been divided into 40 linked cells of alternating channel types as provided in Table 2.2 (Birkhead *et al.*, 2000). Each cell represents a specific channel type

The method used by Birkhead *et al.* (2000) was adopted because the conventional method of computing the energy slopes by computing the generally non-uniform flow profile (Birkhead *et al.*, 1995) may not be easy to apply in the Sabie River. The conventional method is impractical for the Sabie River due to the extensive degree of bedrock control, combined with the complex cross-sectional morphologies and spatial distributions of flow resistance (sedimentological and vegetational) (Birkhead *et al.*, 2000). This creates the need to account for all the local hydraulic controls affecting the energy slope at a particular location along the river, which is not easy to achieve.

The average energy slopes for single thread, braided, pool-rapid, mixed anastomosing and bedrock anastomosing channel types are 0.0012, 0.0013, 0.0020, 0.0029 and 0.0057 respectively (Table 2.2). Thus the energy slope increases from entirely alluvial sections (single thread and braided channel types) through intermediate sections of alluvial and bedrock (pool-rapid and mixed anastomosing channel types) to sections with dominating bedrock influence (bedrock anastomosing channel type). This is an indication that the high gradient and bedrock boundaries/projections associated with bedrock sections of the Sabie River are zones of high boundary shear stress and/or stream power. This is comparable to the situation in Narmada River, India where upstream bedrock sections have been reported to have high gradients and high bed shear stress and unit stream power (Gupta *et al.*, 1999). Thus channel reaches with steep gradients have high energy for moving the sediment.

The alluvial reaches with relatively low gradients have low energy slopes (Table 2.2) and therefore low boundary shear stress and stream power. Thus low sediment transport is experienced in these regions with high sediment accumulation potential. Because of their alluvial nature, these reaches contain a store of sediment that can be eroded by any discharge event with the potential to erode sediment. Mostly the sediment eroded from the bedrock areas accumulates in these reaches. The energy slopes for the given discharge events can thus be viewed as hydraulic drivers of sediment transport and storage.

Since the sediment transport potential is directly related to the energy slope, the increasing order of the energy slopes for the different channel types correspond to the sediment transport potential hierarchy for the same channel types. This hierarchy is represented in two-dimensional form in Fig. 2.7.

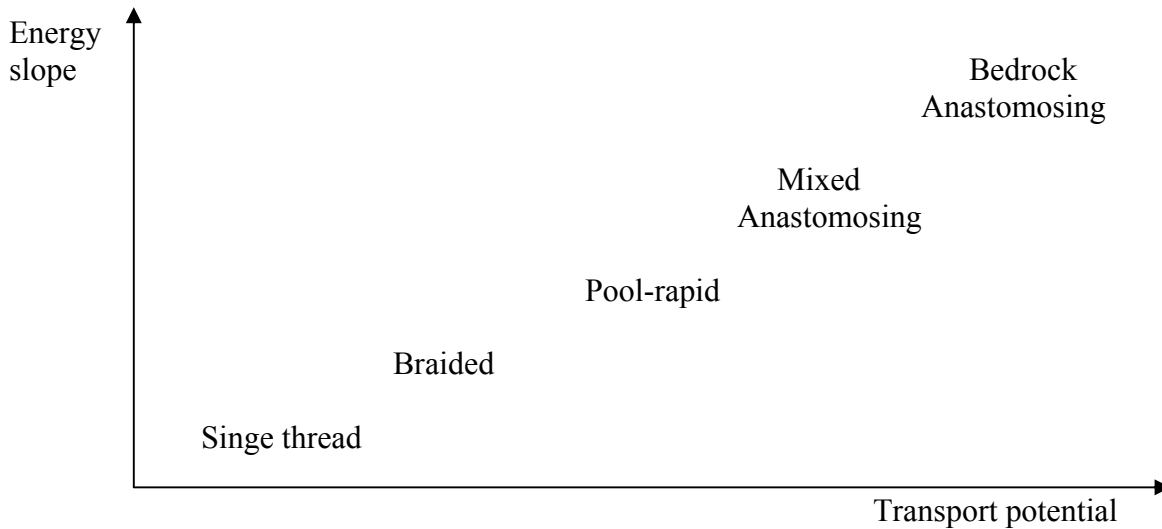


Figure 2.7: Representation of sediment transport potential in relation to energy slopes for the different channel types

The results of aerial photographic analysis by Birkhead *et al.* (2000) are presented in Fig. 2.8 as the measured relative change in bar area per unit length of the cell from 1940 to 1986. The results show that the braided channel types exhibit the highest individual and average rate of bar growth (5.1%), followed by the pool-rapid (2.3%), followed by mixed anastomosing (1.5%) and bedrock anastomosing (0.3%) channel types. Braided channels represent a clear storage zone whereas single thread channels have limited storage within the channel itself. The information on single thread channel types was insufficient as there were only two single threads, one of which displayed zero and the other 2.4% of the total bar growth, to use as a basis for sound decision making. It can partly be inferred from Fig. 2.8 that the single thread channels show very little change and therefore little dynamic storage, which could partly be contributed to by limited form roughness in these channels. Except for the inadequate results of single thread channel type, the results of bar growth show clearly that channel types identified on the basis of energy slope criteria

as high sediment transport potential channel types have low sediment storage potential (bedrock dominated channel types). Similarly those identified on the basis of energy slope criteria as low sediment transport potential channel types (alluvial channel types) have high sediment storage potential. This justifies the reasonableness of energy slope as criterion for indicating the order of increase or decrease of relative values of sediment transport and storage potentials for the different channel types. This means that the energy slope as a multiple of unit stream power is a very important parameter that directly influences sediment transport and storage potentials of different channel type reaches. The proposed sediment storage potential hierarchy is presented in Fig. 2.9.

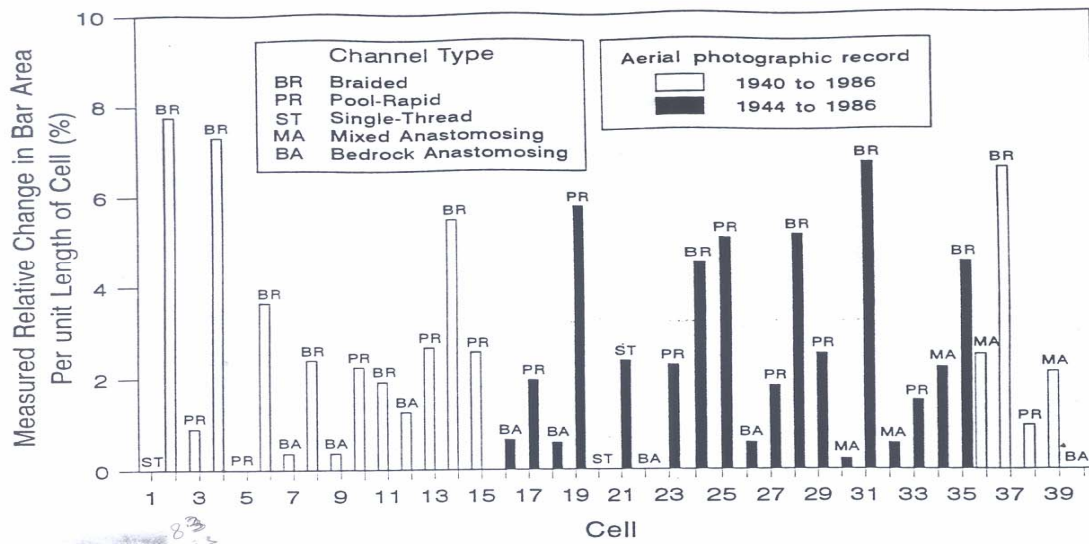


Figure 2.8: Change in bar area per unit length of cell as a percentage of the total change along the Sabie River (KNP), measured from the 1940/44 and 1986 aerial photographic records (Source: Birkhead et al., 2000).

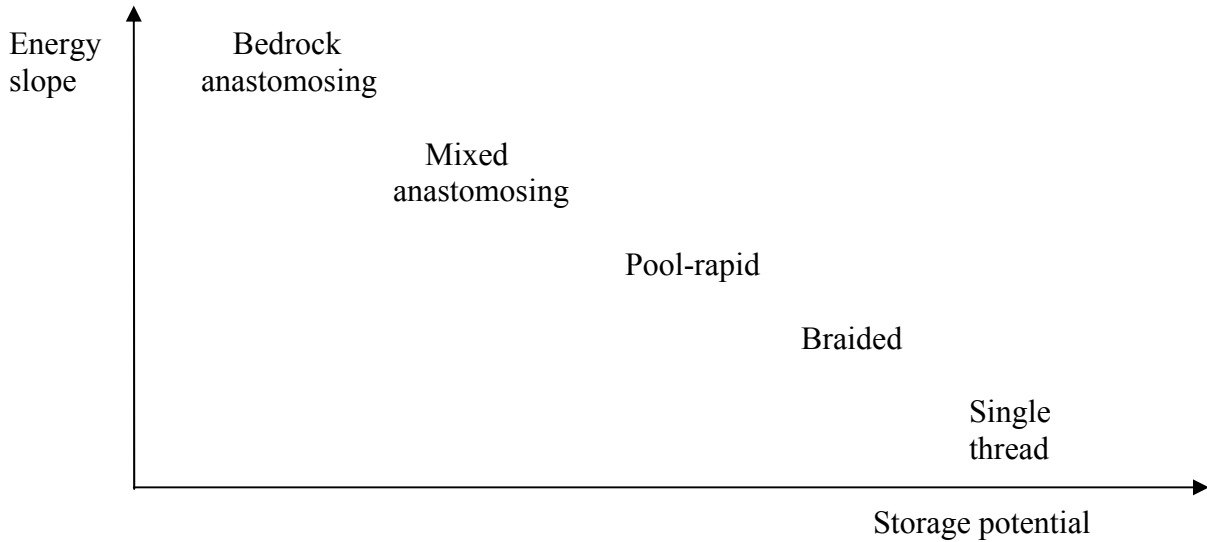


Figure 2.9: Representation of sediment storage potential in relation to energy slopes for the different channel types

2.9 A model suitable for simulating sediment dynamics in bedrock-controlled Rivers

The inconsistency of model results of Birkhead *et al.* (2000) (Fig. 2.10) and those derived from the aerial photographic records (Fig. 2.8) show the method of Ackers and White (1973) together with resistance criteria based on Manning's roughness coefficient was inadequate for modelling sediment movement and storage in bedrock-controlled rivers. Their model results show the highest potential sediment transport in alluvial single thread and braided channel types, whereas the lowest bulk transport is for the bedrock anastomosing channel type. This means that the alluvial channel types generally erode, while bedrock dominated channel types generally deposit. This contrasts with the information on aerial photographs that show alluvial reaches as zones of net sediment accumulation and bedrock dominated reaches as zones of net sediment transport. The photographic observations are consistent with the expected sediment transport and storage behaviour based on the direct correlation with the energy gradient of each channel type (Table 2.2). This confirms the inadequacy of the conventional models of

applied stream power and shear stress developed for alluvial channels in predicting sediment movement and storage in bedrock-controlled rivers.

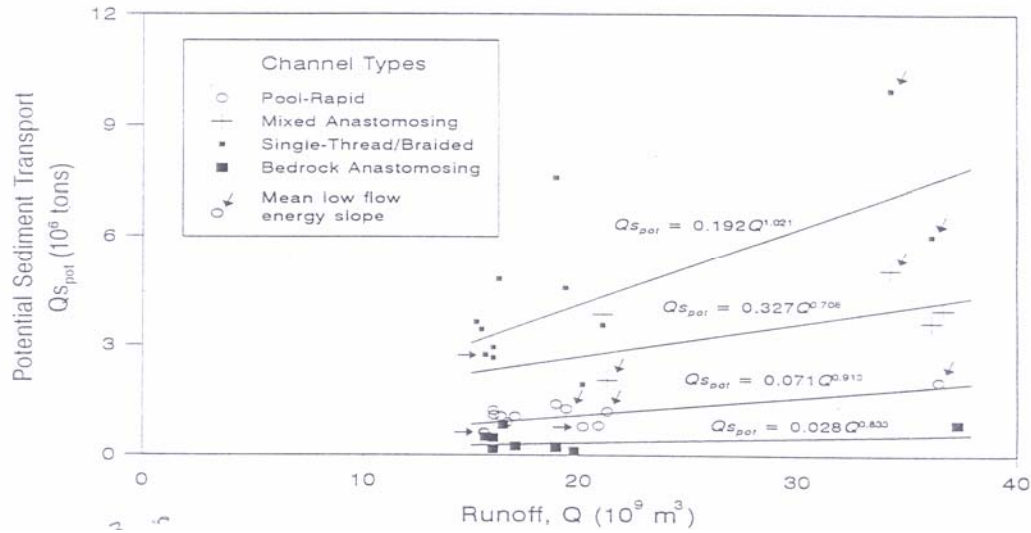


Figure 2.10: Runoff vs potential sediment transport for each of the 40 cells along the Sabie River over the period 1940 to 1986 (Source: Birkhead *et al.*, 2000)

The complexity of bedrock-controlled rivers in terms of bedrock outcrops, vegetation growth and the distribution of sediment in the form of different types of bars make it impractical to rely on the method of Ackers and White. Ackers and White (1973) is the method most frequently used to predict sediment transport in alluvial river reaches.

Since sediment transport in bedrock-influenced semi-arid rivers have been observed to be episodic, a sediment budget approach based on sediment storage changes associated with discrete discharge episodes in the various sediment storage units is suitable for simulating geomorphic changes in such river systems. The influence of the bedrock structures and stabilized alluvial deposits as well as other resistance features such as vegetation need to be considered within the broader context of the characteristics of the sediment storage units e.g. channel types or morphologic units. The bedrock structures and stabilized alluvial deposits are therefore defined through geomorphological hierarchical classification systems e.g. channel types in the Sabie River. A model that considers the different storage units e.g. channel types therefore accounts for the variation in sediment

transport and storage associated with different bedrock structures and alluvial deposits. Bedrock structures, stabilized alluvial deposits and vegetation are resistance features that influence shear stress/stream power distribution and hence impact on sediment transport and storage.

Sediment accumulation is not solely a function of the absolute stream power at a particular point (Moon *et al.*, 1997). Accumulation occurs where there is a reduction in channel transport capacity (i.e. mass of sediment transported through a cross-section per unit time) relative to that upstream (Moon *et al.*, 1997). This means the sediment available in storage in each of the different channel types is as important as the stream power in determining the sediment transport potential. The relative differences in volumes of sediment accumulation in the different channel types should therefore be integrated with that of energy slope variations in defining the sediment transport potentials for the different channel type reaches. However, since the sediment accumulations in the different channel types in bedrock-controlled rivers mostly occur in discrete units (e.g. bars) distributed in locations of low shear stresses, the effect of these discrete alluvial accumulations is therefore integrated in the energy slope. This means the sediment transport potential defined on the basis of energy slopes (or unit stream power) indirectly takes cognizance of the impact of the variations associated with the quantity of sediment available in the storage units on the sediment transport potential. For example, a bedrock-anastomosing reach with high sediment transport potential and low sediment accumulation has a high energy slope. This is distinctly different from an alluvial channel reach with low sediment transport potential and high sediment accumulation rate, which has a low energy slope. Higher volumes of sediment accumulation in discrete units distributed all over the channel results in higher resistance that backs up flow and minimizes the changes in the flow depth profiles, resulting in low energy slopes.

The quantitative variations of the sediment accumulations in the different channel types can be accounted for by constructing a model that simulates the sediment dynamics of the different channel types on the Sabie River, for example. A model that accounts for the variations in sediment transport potentials for the different channel types on the Sabie

River has the potential to simulate sediment dynamics through the storage units. As explained in the previous paragraph the variations in the sediment transport potentials, based on the unit stream power (or energy slope) variations, are closely linked to sediment accumulations and their distribution. A sediment dynamics model constructed on the basis of such sediment transport potentials makes it possible to understand and characterize the individual impacts of the different channel type reaches in accumulating and transporting sediment. The sediment dynamics simulated in the different channel type reaches by specific discharge episodes can be linked to the geomorphic changes observed through aerial photographs or satellite images. This will make it possible to simulate the geomorphic responses associated with individual discharge events in the different channel type reaches of bedrock-controlled rivers with such channel type reaches such as the Sabie River.

2.10 Summary

Literature review has linked the differences in estimated sediment transport rates by different sediment transport methods to the differences in the theories of sediment transport. It has been emphasised that the estimation of the mean sediment transport rates in complex river systems (bedrock-controlled rivers and braided rivers) is complicated by significant changes in channel morphology over short spatial extents. This means that the rates of sediment transport are variable within short distances and therefore it is unrealistic to estimate mean transport rate for the entire river reach.

The spatial changes in morphological cross-sections means that changes in sediment transport should only be measured at short spatial extents over homogeneous morphologies of nearly uniform sediment transport rates. The variations in sediment transport rates are due to the variations in bed shear stress, which varies with the variations in cross-sectional morphologies. The review recommended the estimation of morphological changes at short spatial extents where the channel characteristics are appropriately homogeneous and representative. This means the entire longitudinal cross-section of the river has to be divided into distinct morphologies on the basis of channel

characteristics for purposes of observations and modelling. Modelling sediment movement and storage in terms of the average sediment transport and storage potentials of sediment storage units with similar sediment transport and storage characteristics has been recommended.

The high cost implication of monitoring sediment storage changes at short distances and the measuring inaccuracies associated with inadequacies of the measuring devices have also been discussed. The episodic nature of both sediment supply and flow has been briefly discussed to elucidate the role played by event based temporal changes in sediment supply and stream power on morphological changes.

The underestimation of sediment supply from the catchment into the watercourses using sediment delivery methods has been shown to lower the accuracy of the estimated sediment transport rate from sediment transport models. The review has shown further that the interaction of sediment available with discharge magnitude and the physical condition of the channel (morphology of the channel) influence erosion and deposition and consequently the geomorphology of the channel for any given sediment size(s). The temporal changes in channel morphology have been shown to result from the temporal fluctuations in the balance between local transport capacity and sediment supply.

The effect of alluvial and non-alluvial features on flow hydraulics (e.g. through oscillatory responses or flow perturbations or backup of flow or by acting as constrictions and expansions) has been explained.

The characteristics of bedrock-controlled rivers in terms of their diverse geomorphology, flow hydraulics and sediment transport and storage characteristics have been described. The Sabie River has been used as an example to show the inability of the conventional models of sediment transport and storage for alluvial reaches to simulate sediment storage changes in bedrock-controlled rivers with complex geomorphology and flow hydraulics. It has also been established that the energy slope as a multiple of the unit stream power and the variations in sediment transport and storage in the different channel

types are important parameters controlling the sediment transport and storage potentials of the diverse sediment storage units. In conclusion, the need for a sediment budget model for bedrock-controlled rivers based on sediment transport and storage potentials of discrete discharge episodes for each diverse sediment storage (morphology) unit has been established.

CHAPTER THREE

MODELLING CONCEPTS AND APPROACH

3.1 Preamble

The concept of inverted episodic sediment budget model, its suitability in modelling sediment movement and storage in rivers of complex morphology such as bedrock-controlled rivers and its links to ecosystem management is explained. The superiority of episodic models in linking the cause to the effect is also highlighted.

The proposed theory for episodically routing sediment in bedrock-controlled rivers and its justification is presented in this chapter. Arguments supported by literature are advanced to rationalize the need to produce process-based models of geomorphology at a scale of resolution consistent with the intended use of the results. The translation concept has been included in this chapter to account for both sediment movement in translation reaches and differences in sediment arrival times (sediment velocity) for sediment of different sizes and possibly densities in bedrock-controlled rivers.

3.2 Conceptualization questions

In conceptualizing how sediment moves and deposits a number of fundamental questions come to mind. Typical conceptual questions aimed at understanding sediment dynamics in bedrock-controlled rivers in order to develop a model for ecosystem management are:

- (1) How does the interaction of discharge, local sediment supply to the reach, sediment characteristics and the channel morphology affect sediment transport and storage?
- (2) What scale of resolution is appropriate for modelling the movement and deposition of sediment aimed at ecosystem management?

To answer these questions we must develop deep understanding and insight with regard to what motivates the movement of sediment and what controls the deposition. This is fundamentally important because the elucidation of the temporal and spatial dynamics of

sediment transport and storage on the basis of interacting processes constitutes a fundamental prerequisite for planning and managing the ecosystem dynamics.

3.3 Process geomorphology in relation to time and space scales

Process geomorphology is the study of the processes of erosion and deposition that fashion the landform, their mechanics and their rates of operation (Chorley et al., 1984). Theoretical developments of process or dynamical geomorphology started after 1950. There were attempts to reconcile the time scale of observable and mechanically explicable processes with the spatial scale of classically considered landscape (large-scale landscape) without much success (Strahler, 1952; Church, 1996). A substantial consensus emerged, instead, to constrain the spatial scale of enquiry to match the time scales of observable processes (Church, 1996). This paradigm allows field observations to be made at very local sites and some important observations to be moved to the laboratory.

The theory of sediment transport in rivers is derived from principles of process geomorphology. The theory supposes that the river moves loose granular material (sediment) over the bed of the stream due to the shear force applied by the flow on the bed (Eq. 3.1).

$$g_b = f[(\tau - \tau_o) / D_*] \quad (3.1)$$

where, g_b is the bed load (traction load) transported per unit width of the channel; f is a function of; τ_o is the threshold stress for sediment movement; D_* is the representative diameter of the transported sediment, and τ is the shear stress (tractive stress) imposed on the bed by the flow of water. The shear stress, τ is given by equation (3.2):

$$\tau = \rho g R S_e \quad (3.2)$$

where, ρ is the density of water; g is the gravitational acceleration; S_e is the energy slope and R is the hydraulic radius. The hydraulic radius is defined as the ratio of cross-sectional area to wetted perimeter.

The tractive force approach to sediment transport (Eq. 3.1) is empirical and not mechanically rigorous. A substantial range of the results that have been imported into or developed within the 'process' geomorphology of recent decades are highly parameterized (Church, 1996). Many of the results are, indeed, no more than empirical scale relations (Church and Mark, 1980), with different parameters for different conditions. Whilst the tractive force formula has the appearance of a classical Newtonian force-response equation, it must be recognized that conditions at the stream bed are much too complex to admit more than an empirical correlation at the specified scale of examination (Church, 1996). Furthermore as noted by Church (1996) the scale of resolution of the results is further limited by the fact that:

- The channel-scale measurements that underlie the assessment of shear stress are substantially averaged in time and, often, in space; and
- The simple description of the sediment boundary ignores important structural characteristics of the sediment surface.

The poor resolution of the results generated from the empirical tractive force approach to sediment transport has led to the criticism reported in Church (1996) that process geomorphology represents merely a kind of functionalist thinking that - whatever its merit in the engineering arena - is not good science at all because it does not approach the 'true' phenomena.

Church (1996) finds this criticism of functionalism not very helpful as it ignores the fundamental constraint posed by the space and time scales at which observations, and the consequent theories, are pitched. Important mechanical constraints upon the nature of the sediment transport process occur at scales that are below the resolution of most of the observations made in geomorphology until very recently, and well beyond the descriptive capacity of simple mechanical models of the kind that underlies the engineering approach to sediment transport in rivers (Church, 1996). Furthermore, the space and time scales of observation constrain the structure and physical content of functionalist theories through their control of the resolution of information in the theory and our theoretical construction of order in nature is bound by the tyranny of the scales (Church, 1996). The author acknowledges, however, that whether a particular scale of enquiry is enlightening

or practically helpful is quite another question. This, of course, opens the possibility that a coherent theory pitched at one scale may be subject to fundamental criticism in light of criteria derived at different scales (Montgomery, 1991).

Though a process-based model may not apply directly to conditions that it was not developed for, i.e. at different temporal and spatial scales as argued in the preceding paragraph, it gives an indication of the physical and mechanical processes that need to be considered at different temporal and spatial scales. Reasonable assumptions and approximations allow us to embed theoretical descriptions within systems of phenomena drawn on significantly different scales (Church, 1996). Functionalist paradigm is founded on the necessity for theories to be mutually consistent across different scales. It is also important that the temporal and spatial scales of observation are within human perceptible range of observation (metres to millimetres and hours to seconds). In essence, the cause and effect must be observable and measurable.

Church (1996) referred to scales at which theory construction is feasible as commensurable scales. He defined commensurable scales as scales at which, within the resolution set by the dimensions and by our observing methods, information transfer can be detected within the landscape or the system under study. It is upon the basis of observed information transfer that theory can be constructed about the behaviour of the system and that causes and effects can be assigned (Church, 1996).

The answers we get from process-based empirical solutions may not be accurate but signal rational quantifiable change in processes linked to the cause. The universality of the assumptions inherent on the physical and mechanical control/processes and the exhaustive consideration of the cause-effect relationship improve on the resolution (accuracy) of the model. This thesis will make it clear that the modelling approach and its inherent resolution are dependent on the purpose of the model results.

The resolution of the information available determines the resolution of theory development and explanation. A key to understand the changing theoretical basis is to

recognize that resolution governs what we can observe about structures in the system and what we can record about the evolution of those structures. The latter author argues that when we have many, more or less rapidly evolving structures we know relatively little about each one - certainly too little to appreciate the individual nuances of its development and to assign specific antecedent causes, we adopt statistical characterization of what we observe. At the other extreme, we may observe only an interval in the evolution of a major structure, our description becomes highly contingent (Church, 1996). Thus the resolution of the information available limits the method used to analyze it and the accuracy of decisions that can be made from it. Church (1996) makes it clear that we observe a different sort of order at different scales. The essential constraint upon the character of information resides in the interaction between the resolution of observations and the information requirements for the particular mode of explanation (Church, 1996).

Various theories and visual resolutions in hydrology and hydraulics of rivers are applicable at different time and space scales. Two of these scales that are directly relevant to hydrological and hydraulics measurements and modelling discussed in Church (1996) include:

- **At scales of order 10^0 m and 10^0 s (1 metre and 1 second)**

At this scale hydrologists can measure eddies (velocity currents) in the river with appropriate velocity meters. The spatial scale is within an order of magnitude of that of the channel itself, and the shaping effect of the channel upon the flow can be observed. If the boundary is compliant (alluvial or, at least, erodible by the ambient currents), the configuration of the flows will eventually reshape the channel. This is the scale at which classical sediment transport theory, as exemplified in equation (3.1), is straightforwardly applied. Measurements are obtained at individual points on the bed of velocity, shear stress, and sediment flux over the adjacent boundary. The eddy scale phenomenon varies sufficiently slowly to permit classical mechanical

descriptions based on average quantities, even though the individual flow structures remain transient (turbulent scale problem).

- **Scales of order 10^1 m and 10^4 s (about 3 hours)**

These are the spatial and temporal scales of normal human perception (at least, of rivers). Most geomorphological change happens within a relatively short time, so the relevant time scale for observing geomorphological processes is that of ordinary perception of events, 10^1 m and 10^4 s. We consider the mean flow and sediment transport in a reach at this scale. This is the scale of usual application of hydrological and hydraulic measurements. At this scale, we are close to a mechanistic view of river channel evolution, a result of intense geomorphological interest. It is also the scale at which most attempts have been made to apply classical sediment transport theory to understand river channel evolution. Moreover, it is now possible to obtain information about the sediment transport process by examining sequential changes in channel morphology. This may be much more relevant, geomorphologically, than direct flux measurements. However, the further averaging that is inherent in the observations can introduce bias into the results if they are viewed only at this scale, since we no longer see the mechanistically conceived transport process. Nesting of measurements in adjacent scales is a means to minimize this problem which represents an important connection between scales of enquiry. The averaging arises from the space and time limits of resolution; the bias may arise when changes beyond the limit of resolution are not reflected in the average. An example may be compensating scour and fill in a river bed.

From the geomorphological viewpoint, shorter-term phenomena that occur within human synoptic scales (10^1 m and 10^4 s) are effectively averaged (Church, 1996). This is especially so if the short time is characterized with short time turbulent episodes (discussed in section 3.5).

The sediment transport process being developed in this study is on the basis of integrated time and space sediment storage changes (morphological changes) for individual discharge events. The method to be described later is constructed on the basis of time and space averaged morphological changes associated with the discharge episodes and therefore closely links mechanics (at coarse-scale of resolution) to morphological changes in defining the sediment transport process.

Some of the most important characteristics of sediment transport process are the velocity of sediment transport and the rate of geomorphic change. Church (1996) in his theoretical construction of scales of resolution highlighted the relationships between these scales and the sediment transport velocity. The theoretical concept of sediment virtual velocity and its control on geomorphologically significant time and space scales is a fundamental concept for deciding on geomorphologically sensible scales of resolution. It is probable that a good deal of what happens on shorter time scales and more restricted space scales than those of sediment virtual velocity is not of direct interest geomorphologically (Church, 1996).

In the fluvial system at very local scales, the velocity for material transport is the characteristic velocity of water (and entrained sediment), about 1 ms^{-1} (Church, 1996). Even at the channel scale (the scale of 'ordinary' perception), the velocities of water and sediment reported in many studies have diverged significantly. Sediments spend most of their time in storage - during which they constitute the visible morphology of the landscape, with their transfer rate according to literature reviewed from Church (1996) defined by the virtual velocity. For example the virtual velocity can be defined by the linear dimension along which sediment transfer occurs - such as the length of a river channel. Virtual velocity is equivalent to linear dimension/residence time. In other words, virtual velocity of sediment movement in the system is the time-averaged rate of displacement. Within stream channel virtual velocities on the order 10^{-4} - 10^{-7} ms^{-1} are typical for bed material (these values are the same as 1 m to 1000 myr^{-1}) Church (1996).

3.4 Episodic modelling of sediment transport and storage

The state of in-channel biodiversity, such as vegetation establishment and growth, is linked to physical variables such as flow and geomorphic diversity. Flows of different magnitudes disturb in-channel habitat to different levels of magnitudes. In recognition of this, Nicolson (1999) classified flows responsible for different geomorphic responses into categories of low, medium and high flows. This move recognized the need to treat events of different geomorphic influences discretely.

One of the advantages of modelling in terms of discrete events is that it can permit ecosystem management decisions to be made from the responses of the in-channel habitat and biodiversity to individual discharge events. The modelled geomorphological processes or sediment storage changes correspond to the time scales of individual discharge events at which it is possible to observe geomorphic changes in the channel for the validation of the model.

Bed load sediment transport does not occur all the time and across the whole river reach but mostly occurs in response to change in shear stress distribution or dynamic interaction of individual discharge events and sediment supply or sediment availability. The preceding statement is based on the notion of sediment transport and storage being episodic. This means that sediment transport and storage occurs in response to individual discharge events with the potential to erode or store sediment. Thus modelling of sediment transport and storage can be achieved by using the discharge hydrograph of discrete events. Alternatively, modelling of sediment transport and storage can be accomplished in terms of independent discharge episodes that last for some time before increasing or decreasing to another discharge level.

Not much has been done on episodic modelling of sediment movement and storage in bedrock-controlled channels to the author's knowledge. Nicolson (1999) initiated the leading work in episodic modelling in bedrock-controlled channels. His study used episodic sediment transport and storage phenomena to qualitatively simulate the

dynamics of the channel sediment budget using time series of flows. In confirming the results of his model, he established striking similarities in sediment movement and storage between the episodically simulated model and the observed patterns in the East Fork River. Changes in bed-material cross-section in riffles and storage areas had been found to be closely related to changes in discharge pulses (Meade, 1985). This thesis therefore views episodic modelling of sediment movement and storage as a fundamental contribution towards the search for a simple viable method that routes sediment in environments where the flow behaviour is temporally and spatially difficult to characterize due to complex morphology. This is in addition to the temporal and spatial complexities of sediment availability in the different sediment storage units in such environments.

Due to temporal fluctuations in flow and temporal separation of discharge events, the discharge pulses responsible for episodic sediment transport and storage may follow each other closely or occur after some time interval. The intermediate period of sediment immobility between successive discharge pulses constitute a period of stable sediment storage, as significant sediment transport may not occur until an episode of movement recurs. To understand and model the channel sediment dynamics resulting from independent discharge events there is therefore the need to model the sediment movement and storage until stable sediment storage state is achieved.

The importance of episodic geomorphic models of landscape evolution is outlined by Schumm (1980). Episodic models capture the understanding of the functioning of geomorphic systems over short spans of time. This is fundamentally different from the development of an understanding of the erosional and depositional evolution of landforms through geologic time. Understanding the functioning of systems requires dynamic models that are capable of identifying processes and modelling their effects on the system in order to predict the system behaviour (White et. al., 1993). The same authors argue that the move towards models that depict the dynamics of the system must be process-based, as systems respond to processes. According to Schumm it is the details of landscape evolution that require elaboration and explanation if traditional geomorphic

problems are to be solved, and if geomorphic research is to be of value to those who are managing and attempting to control various components of the landscape (rivers, slopes, floodplains). Furthermore, the average rates of erosion or deposition are misleading in the sense that they do not clearly display the complexities and the variability of the erosional and depositional development of landforms.

At small space and time scales (high-resolution) phenomena are recorded in sequences which describe very large numbers of characteristic events (Church, 1996). The statistical analysis of processes associated with such large number of events is aimed at producing the average geomorphic response of the series of events. Such analysis gives geomorphic change as an average of a number of stochastic processes and does not isolate the geomorphic response associated with specific events. This does not account for the fact that some of the events may not contribute decipherable geomorphic change. Thus, at high resolution, it is not clear that all information possesses coherent patterns of geomorphological interest (Church, 1996). A modelling/monitoring scale of resolution that looks at the geomorphic responses of discrete events is therefore superior as it allows geomorphic change to be ascribed to the relevant cause.

3.5 Scales of flows and geomorphic change

Episodic movement can be linked to the stochastic nature of floods/discharge events or to turbulent episodes. Most sediment transport is driven by stochastic precipitation events in which masses of sediment released from hillslopes travel discrete distances down channels and stop (Dietrich and Montgomery, 1998). Flood episodes can be linked to discrete precipitation/rainfall events. The pulses of sediment released by these events travel progressively downstream (Dietrich and Montgomery, 1998; Heritage and Van Niekerk, 1995; Meade et al., 1981) with sediment storage occurring at local sites of reduced shear stress or increased resistance to transport.

At a more detailed level of resolution, discharge fluctuations constituting turbulent episodes within a flow profile may be used in modelling sediment movement and storage.

This would involve capturing detailed flow characteristics of individual flood episodes. The time and space scales of turbulent motions and turbulent structures are seconds and millimetres (Church, 1996). Further difficulties would be experienced in trying to link individual turbulent episodes/pulses to the physical changes in the channel in complex river systems such as bedrock-controlled rivers.

Studies using statistical concepts that relate average geomorphic changes to the integrated effect of a series of turbulent episodes that occur over large time and spatial scales have been attempted. Such statistical methods lack the potential to isolate individual effects of turbulent episodes. Church (1996) gives a clear picture of such attempts and highlights the inability of models built at such scales to operate within ordinary human perception scales in linking observed physical features to the individual turbulent episodes. This introduces inconsistency in scales, as what is observed cannot be linked to an immediate cause but to an average effect of a series of previous causes. This means that the description of the phenomena remains essentially statistical through averaging processes and simple patterns of cause and effect cannot be traced.

Church (1996) makes it clear that the development of theory or use of existing theory is not tied to general scales. However, once the theory is developed for a set scale it becomes a constraint. This implies that in any model construct it is important to consider the temporal and spatial scales within which the concept under study is viable. This means that a concept developed at one scale may not be applied directly to another scale without modification or accounting for the scale effect.

Whilst geomorphologists have embraced a very wide range of space and time scales to order - thence 'explain' - observations, there has not been (to my knowledge) any organized attempt to construct the subject about those scales in conscious recognition that the character and quality of explanation will thereby be systematically affected (Church, 1996). The author goes further to concur that the space and time scales affect the character and quality of explanations. Thus any serious geomorphological work needs to operate within a defined scale framework. However, this thesis does not view modelling

scales strictly in terms of time and space but in terms of their flexibility in allowing a wide range of choices or management decisions even in a situation of limited information. In other words, this thesis is more concerned with pragmatic scale resolutions that are not rigid and allow theoretical development for decision making at different hierarchies. This means that you can develop a theory at a coarse scale of resolution either to filter the decision options or to act as a starting step for identifying information to be collected for fine decision making.

The episodic concept envisaged in this thesis, uses flood episodes (discrete hydrographs) linked to discrete rainfall events. Though modelling in terms of discrete discharge hydrographs (flood episodes) results in low-resolution model compared to a model based on turbulent episodes, the results are easy to link up with the physical processes. A model built on the basis of flood episodes apart from making it possible to model complex cases can allow the hydrological processes of change to be linked to geomorphic processes. Thus, management decisions that link geomorphic changes to discrete discharge events (flood episodes) can be made. For example it makes it possible to link a flood of a given magnitude and duration to observable geomorphic changes associated with the flood. Thus, if a similar flood is projected to occur in the future, the associated geomorphic changes can be predicted at the modelling scale of resolution.

3.6 The concept of low-resolution modelling

Walters and Korman (1999) classify modelling scales of resolution into very fine-grained, high-resolution models and coarse-grained, low-resolution models. High-resolution models are focused on providing very precise predictions for a small set of indicators. High-resolution model requires fine details or detailed data (information) for setting up the model, calibrating the model and verification of the model. Low-resolution models provide relatively imprecise predictions for a large suite of indicators (for example various components of an ecosystem) over management-relevant time and space scales. Low-resolution model may be built, calibrated and verified on the basis of scanty data. The term *grained* will be replaced by *detailed* in this thesis.

The guiding principles in choosing modelling scales of resolution are not necessarily disciplinary. The model structure and variables need to be defined in reference to policy issues rather than scientific interests and disciplinary traditions (Walters and Korman, 1999). This thesis views this sentiment as a pivotal principle that should guide management-oriented models. In other words, the resolution at which the model is built should be in response to the management objective. It suffices to build low-resolution model if it provides sufficient answer to the management problem. Such a model may reduce computational complexity and yield an efficient and cost effective tool of management that is simple and easy to apply.

The concept of coarse scale modelling permits modelling of complex systems that may not be explicitly and completely represented in mathematical terms. Such systems include large-scale systems, systems with complex responses and systems with multiplicity of interacting variables. The characteristics of the latter two systems are typical of bedrock-controlled river systems.

For certain types of systems and decisions, coarse scale models are adequate. For example the management decision required may involve primary policy choices on large-scale objectives, such as "restoration of natural ecosystem function" or "maintenance of biodiversity". Prediction of some sort is implied by the very notion of "choice" (choices can only be compared by making some assertion, that is, some prediction, about the consequences of each), but it is a serious logical error to suppose that prediction must be quantitatively precise (Walters and Korman, 1999). The latter authors argue that for policy choice, what really matters is only that the prediction method or model be accurate enough about alternative outcomes to correctly order the choices; most often, correct ordering requires nothing more than knowledge of qualitative outcomes (existence and direction of responses) or ranges of outcomes (for example, policy A will produce at least twice the response of policy B). This means that the really valuable ecosystem models generally are not those that make precise predictions, but rather those that guide and focus policy choice by helping to "prune" or "screen" options; generally the power of such models in decision making comes not from the numbers they generate, but rather

from the way they help structure clearer, stronger qualitative arguments about the relative efficacy of various options (Walters and Korman, 1999). The latter authors recognize that an exception to this rule occurs where a successful policy must meet some absolute standard.

It is important to emphasize that management decisions do not necessarily require low-resolution models. There may be need for high-resolution models to come up with precise and reliable predictions. Walters and Korman (1999) recognize the pressure that is being exerted on ecosystem modellers to come up with fine detailed models. The appropriate modelling resolution can therefore be viewed in terms of the management objectives, the time required to produce the solution, the resources available, the simplicity of application in making management decisions and the cost implications. In some cases high-resolution models do not find direct application in making management decisions unless they are simplified and generalized. Therefore building a generalized low resolution model that captures the fundamental primary decision making variables may be viewed as superior to fine detailed model in decision making of such nature. Such a model may not necessarily ignore the fundamental variables of change. However, it may lump together related variables in representative parameters.

This thesis therefore views low-resolution modelling in terms of management objectives, the need to accelerate decision and simplify decision making processes and as a substitute to high resolution models in modelling sediment dynamics in complex river systems such as bedrock-controlled rivers. Such a system has a multiplicity of variables that display complex interactions and it may therefore not be possible to obtain detailed data on all the interacting variables. This calls for a modelling strategy that can cope with inadequate or lack of information but still permit fundamental management decisions to be made.

Landscapes are affected by a complex interplay of processes and are influenced by significant spatial heterogeneities, such that there is indeterminacy in landscape form at specific local sites, but overall land forms tend toward a most probable state (Leopold, 1995). The complexity of processes and forms implies that relationships between form

and process based on detailed process laws may not be easily developed (Dietrich and Montgomery, 1998). The most probable state of Leopold and use of less detailed process laws can be construed to mean the ultimate stable state (section 3.9) and low-resolution model respectively in the present approach.

Literature reviewed from Dietrich and Montgomery (1998) reveals that Rodríguez-Iturbe and Rinaldo (1996) generated network structures by a computational procedure that does not simulate the actual simultaneous routing of water and sediment off the landscape. The problem here is that the transport laws operate over finite scales and when related to real landscapes have specific and often limited ranges in real parameters (Dietrich and Montgomery, 1998). The use of transport laws in simulation of landscapes can therefore be considered as coarse scale (Dietrich and Montgomery, 1998). This modelling approach is comparable to the sediment routing model being developed in this thesis (section 3.9) that uses bulk sediment storage characteristics of steady discharges and logical sediment budgeting rules in sediment storage units of bedrock-controlled rivers e.g. reaches, channel types, morphologic units etc. This is unlike high resolution conventional simultaneous routing of water and sediment at highly localized sites (small scale). Such a model, though less rigorous in consideration of local process-form responses, following the scale-dependence arguments of Dietrich and Montgomery (1998) is more generalized as the erosion laws are not calibrated for specific local sites. The erosion laws can be applied at any storage unit regardless of its size provided it is similar to those for which the discrete discharge characteristics have been determined. The erosion laws are such general descriptions of the phenomena (Dietrich and Montgomery, 1998) and can therefore be applied to any conditions supported by the phenomena.

The departure from detailed study of local sediment accumulation and erosion implies a low-resolution modelling approach. The value of such an approach is that the influence of the primary physical processes of change is not marred by the fine details of the model parameters. Information on geomorphic change is extracted from process-form interactions using parsimonious number of parameters that can be related to processes of

change. Though, Dietrich and Montgomery (1998) recommend the use of transport laws in coarse-scale simulations of landscapes, they note that it is not clear that this warrants a process-based interpretation of the model results. Such interpretation of the model results can be achieved by a modelling approach linking geomorphic change to processes of change. The proposed sediment budgeting method based on sediment storage characteristics of discrete discharge episodes is one such approach (section 3.9). The method relates sediment storage changes to specific discrete discharges as noted later (section 3.9) and therefore captures the major outstanding problem in geomorphology. The routing of sediment in watersheds from the source through the network to the outlet at which the effects of sediment storage are properly accounted for is one of the major outstanding problems in geomorphology (Dietrich and Montgomery, 1998).

The bottom line in this thesis is that if we are able to understand the system's behaviour, we can model it coarsely in terms of simple approximation functions characteristic of the system's behaviour. The interest is not necessarily to obtain the correct magnitudes of indicators of change but to be able to come up with a generalized model framework that can indicate directional change. This modelling strategy would allow modelling parameters derived in the laboratory to be applied in field situations to indicate directional change without necessarily meeting rigorous scaling. This will be attempted in this thesis by parameterizing the inverted episodic sediment budget approach proposed in section 3.9 on the basis of laboratory data (sections 6.3 and 6.4) and verifying the results through laboratory observations (sub-sections 7.5.1, 7.5.2 and 7.5.3). The phenomenon will be developed and verified on the basis of laboratory data due to lack of field data.

3.7 The rationale for modelling bedrock-controlled rivers at coarse scale of resolution

Bedrock-controlled rivers, being of complex morphology and flow characteristics may not be easily modelled on the basis of conventional numerical solutions of partial differential equations as discussed in section 1.1. The local variations of shear stress or stream power make generation of high-resolution models based on shear stress or stream

power impractical, as this requires consideration of all the bedrock irregularities in the computation of the energy slope. This would require representation of all the bedrock irregularities in the model and computation of the energy slope at high spatial resolutions to capture the changes in water surface slope associated with all these irregularities. The physical representation of the bedrock irregularities in partial differential equations may not be possible. Even if the effect of bedrock irregularities are lumped in a roughness parameter and used as a coefficient in the dynamic partial differential equations of Saint-Venant, the accuracy of the partial differential scheme would still be low. Thus the computational result obtained would not be an accurate or an exact solution but an approximate representation of the situation as estimated by the modeller. The calibration and validation of such a model would require a comprehensive measurement of water levels at short spatial and temporal resolutions at and in between the bedrock irregularities. Furthermore in modelling a large river with several bedrock irregularities, the use of partial differential numerical schemes may result in computer memory problems.

What has emerged in the preceding paragraph is that even with a high-resolution partial differential numerical scheme the results of sediment transport in a bedrock-controlled river would represent the system behaviour and characteristics as understood and approximated by the modeller. Thus the requirement postulated in this thesis that a model be based on deep understanding of the system characteristics and behaviour should be the driving philosophy in modelling. What then constitutes the guiding principles on deciding on the modelling resolution and the type of model to build? The modelling scale of resolution and the type of model to build would philosophically be guided by deep understanding of the system behaviour and characteristics. This should result in intelligent representation of the system behaviour and characteristics in a parsimonious manner but still be able to generate solutions that meet the purpose of the model. This requires that the computing capacity of the available facilities, the time frame within which the solution is required and the purpose for which the model is built be taken into account.

Low-resolution models governed by observable physical variables (episodic discharges, sediment supply or sediment available and channel morphology) are proposed for bedrock-controlled channels. The proposed low-resolution models are based on the dynamic interaction of sequences of discrete discharge events and sediment supply or sediment available and the fixed geometry of the reach. This modeling strategy operates with the inherent assumption that bedrock-controlled channels composed of a mixture of alluvial and bedrock reaches are mostly found in steep gradients where the potential to transport the sediment defined in terms of the stream power is not limiting. However, the sediment supply is a limiting parameter. Since the sediment transporting power is available, the geomorphic response can be modelled simply in terms of the sediment budget equation based on the disequilibrium and stable states of sediment storage. Changes in discharge events are considered to motivate internal readjustment towards new states of sediment storage.

The proposed modelling method that uses discharge characteristics as the fundamental flow parameters driving geomorphic change at low resolution will make it possible to model and understand the behaviour of bedrock-controlled rivers at least coarsely. The discharge model is low resolution because it does not account for the energy slope variations in the rising and the falling limbs of the hydrograph. Such a low-resolution model needs to be viewed as a prototype model aimed at approximating the behaviour of the natural system.

This thesis views the proposed low-resolution episodic modelling as a fundamental methodological shift appropriate for river habitat management. In managing the river habitat, the increase or decrease in alluviation is an indicator of the river system's ability to sustain the indigenous biotic species or undergo biotic species metamorphosis. This is because the river managers are interested in knowing either qualitatively or quantitatively the extent to which change in the flow regime (represented by discrete discharge sequences in this thesis) disturbs the habitat or ecological functioning by increasing or decreasing the sediment storage volume. Thus a model that captures the influence of the

change in flow regime on sediment movement and storage is a suitable ecosystem predictive or management tool.

Shear stress or stream power driving sediment movement may be viewed as fine details fundamental to the internal dynamics of sediment transport. However, river managers may not be interested in internal drivers of sediment dynamics but on the primary physical drivers that can be linked to changes in habitat and biodiversity. The type of model that needs to be built for ecosystem management should be geared towards answering questions pertinent to the management of habitat and conservation of biota. Such questions may include:

- If the flow increases or decreases by a certain magnitude and lasts for certain duration, will the sediment volume in the river increase or decrease?
- What is the implication of the habitat change to the biota?

To answer such fundamental management questions, a discrete event driven model built on observable physical parameters may be a better management tool than one that concentrates on the internal dynamics of sediment transport and storage. Attention should be directed to the biological significance of the various quantities in the equations, rather than the mathematical details (May, 1981) for management directed towards biological responses. According to May, concentration in the latter at the expense of the former introduces the risk of losing sight of the real wood in contemplation of the mathematical trees. Thus building a pragmatic model that links the sediment movement and storage to sediment storage characteristics of individual discharges of known magnitudes and duration and that seeks to demonstrate increase or decrease in alluviation can be viewed as a fundamental management tool.

According to White et al. (1993) even a fine resolution model involves lumping together of variables and relationships and some loss of realism. Thus the cost of pursuing such solutions may not be justified. Fine resolution models also lose the generality required of decision-making models as they are geared towards solution of specific problems.

Unlike high-resolution models, developed on the basis of partial differential equations (PDE), low-resolution models in this context involve the use of process-based non-dimensional mathematical relationships and logical sediment routing rules developed on the basis of laboratory results and logical reasoning respectively.

In pragmatic modelling for specific application, the fineness or coarseness of the modeling resolution should be considered as a function of the use the developed product is intended for. As explained earlier in this section, in ecosystem management with the purpose of conserving in-channel bio-diversity, the river managers may only be interested in knowing the directional change of sedimentation, which is a coarse scale of resolution. This contrasts with the fine scale of resolution at which an engineer would computationally model sedimentation for the purpose of inferring the scope at which sedimentation has reduced the dam capacity to generate power. Walters and Korman (1999) present another example of modelling at fine scale of resolution for engineering application. They noted the need for detailed local modelling to represent effects of fine-policy actions, such as strong diurnal fluctuation in releases of water from hydroelectric dams to meet corresponding fluctuations in power demand.

Consider deep pool habitats that provide cover and cool water temperatures to salmon and trout during warm weather months (Kondolf and Wilcock, 1996) as typical bedrock-controlled morphologies. If such habitats are lost to aggradation, it may be sufficient for the river manager to establish the approximate scope of reduction of the volume of the pool and make a decision as to whether a small or a big flow is needed to flush the pool. What the pool manager needs to establish in this case is the relationship between the discharge and sediment storage in the pool. A model built to achieve this is a low-resolution model as it does not need detailed temporal and spatial flow levels data typical of detailed resolution models based on shear stress or stream power. Thus the low-resolution model is viewed in this study as an ecosystem management tool appropriate for managing in-channel bio-diversity. Since the proposed modelling strategy has the ability to show the directional geomorphic change, it is therefore appropriate as a cost-effective geomorphic tool for managing bedrock-controlled in-channel habitats.

3.8 Conceptualization of the model

A sediment transport and storage dynamics model dependent on sediment storage characteristics of independent discharge episodes at the storage unit scale, sediment characteristics and sediment supply has been conceived. The storage unit can either be at the morphological unit scale or channel type scale. The method is viewed as appropriate for modelling sediment movement and storage in different storage units of bedrock-controlled rivers.

The conceptualization of the model was motivated by episodic movement of sediment, spatial discontinuity of sediment transport and storage in bedrock-controlled rivers (section 1.1), and different sediment transport and storage characteristics of different geomorphic types (section 2.8: 2.8.1; 2.8.2). The spatial and temporal complexity of flow hydraulics in bedrock-controlled rivers also motivated the need for a new modelling approach.

3.9 Sediment budgeting philosophy and mathematical treatment

Theories of storage change with time towards a dynamic equilibrium formed the basis for developing episodic sediment budgeting approach. Landform can either be in a cycle of erosion or dynamic equilibrium with operating forces (Schumm and Lichty, 1965). With the passage of time, erosional modification of the landforms affects erosional energy (Schumm and Lichty, 1965; Hack, 1960). The change in erosional energy with time can be related to change in the erosional potential of a specific discrete discharge event with time, along the storage depletion curve. A storage depletion curve is the sediment storage curve showing integrated depletion of sediment from storage with time as erosion occurs towards the ultimate stable state of storage for each discrete discharge event. An inclusive sediment budget model must therefore account for sediment storage changes with time until an ultimate stable storage state.

The underlying sediment budgeting philosophy is that each discrete discharge event erodes or stores sediment towards an ultimate stable state of storage. A model whose essential parameters include the ultimate stable state of storage and change of storage with time (storage depletion curve) can describe this situation. A storage depletion curve is a recession curve. Recession curves often take the forms of exponential decay (Chow *et al.*, 1988). It was found practical to treat the storage changes in the model in terms of scour depth. This is because attempts to develop definitive non-dimensional relationship between volume changes at ultimate stable state and discharge were futile while those with integrated scour depth yielded definitive relationships (section 6.3). This thesis, however, recognizes that more general applications with 3D storage distributions would probably have to use volume directly.

An exponential decay function starting from the initial space available for sediment storage and shifting temporally towards the ultimate stable scour depth for each discrete discharge event has been hypothesized for describing the erosion behaviour associated with each discrete discharge event (Eq.3.3; Fig.3.1). Each discrete discharge event is characterized by a particular value of discharge magnitude and duration.

$$H_{new} = H_{uss} - (H_{uss} - H_{beg}) \exp(-kt^{\phi}) \quad (3.3)$$

where, H_{new} is the scour depth attained at the end of the current discharge event or time step (m); H_{uss} is the ultimate stable scour depth (m); $H_{beg} = H_{prev} - H_{sup}$ is the previous scour depth plus the supply depth (m); H_{prev} is the scour depth attained before the current discharge event or time step (m) (For the initial sediment storage conditions before sediment routing begins, this is the same as the initial sediment scour depth (H_{init})); H_{sup} is the sediment supply depth (m); k is the exponential decay parameter ($\text{sec}^{-0.5}$); t is the time elapsed (seconds); ϕ is the exponent of time elapsed. The sediment supply depth (H_{sup}) is subtracted from H_{prev} as the supply reduces the scour depth.

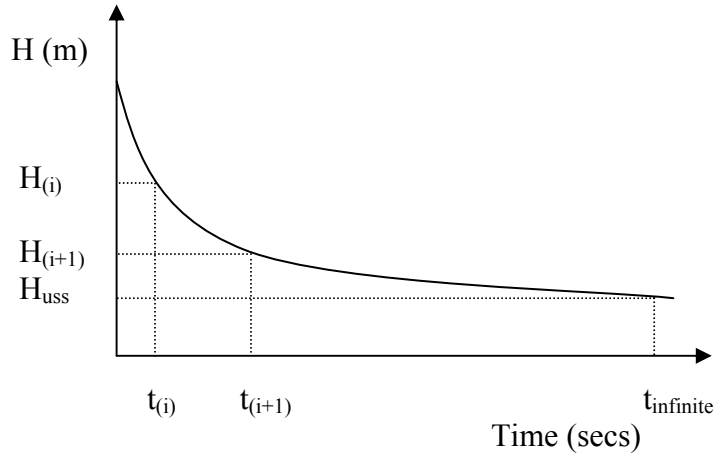


Figure 3.1: Scour depth-time relationship

The storage depletion curve (Fig.3.1) shows that at a time step of $(t_{(i+1)}-t_{(i)})$ a specific steady discharge would erode sediment of scour depth $(H_{(i+1)}-H_{(i)})$ from $H_{(i)}$ to $H_{(i+1)}$, towards the ultimate stable scour depth (H_{uss}) at infinite duration, $t_{infinite}$. This means that the amount of sediment eroded by each steady discharge is dependent on the duration of the discharge. If the steady discharge lasts for an infinite duration, the scour depth would correspond to H_{uss} . The scour depth at which erosion begins ($H_{(i)}$) and the scour depth attained after erosion for the duration of the discharge ($H_{(i+1)}$) correspond to H_{beg} and H_{new} respectively (Eq.3.3). The sediment storage (deposition) towards the ultimate stable scour depth for each discrete discharge event can be accomplished through direct sediment budgeting.

The depth of sediment eroded is converted into volume of sediment eroded through multiplication by the cross-sectional area over which the sediment is eroded. An inverted sediment continuity equation (Eq. 3.4) is used to budget the sediment as the model computes change in sediment storage (ΔS) before applying the sediment budget equation to compute the sediment output (Q_{sout}). Equation (3.4) is inverted from the conventional sediment budget equation (Eq. 3.5).

$$Q_{sin} - \Delta S = Q_{sout} \quad (3.4)$$

where Q_{sin} is the sediment supply either from external source/s and/or from the routing cells immediately upstream.

$$Q_{sin} - Q_{sout} = \Delta S \quad (3.5)$$

Thus the sediment budget model is called inverted because it computes the change in sediment storage (ΔS) before predicting the sediment output associated with each discrete discharge over a given time step. This is unlike conventional sediment routing models that compute Q_{sout} and use it in the sediment budget equation (Eq. 3.5) to compute the change in sediment storage (ΔS).

Conventional sediment models are concerned with predicting conditions for sediment movement, rates of sediment movement and the resulting load of sediment. However, a useful model for modelling channel morphology and habitat change must in addition as explained by Dawdy and Vanoni (1986), predict the change in the channel as a result of erosion or aggradation of the bed and erosion of the banks. The current sediment transport models which are mostly suitable for alluvial channels compute the sediment transport rate before predicting the sediment storage changes. However, these models as partly discussed in section 2.2 have been reported by Dawdy and Vanoni (1986) to suffer from the problems of: (i) unreliable sediment discharge functions, (ii) inadequate formulation of the friction factor of erodible channels, (iii) inadequate understanding of and formulation of bed armouring and its effect on sediment transport, and (iv) inadequate allocation of net scour and net fill in a stream cross-section. Thus these models cannot predict sediment transport accurately and this makes the determination of sediment storage changes (scour and fill) from the computed sediment transport rate highly unreliable.

The modelling approach used in this study models the result of sediment transport in terms of sediment budget, or sediment storage changes. This makes much more sense in modelling channel morphology and habitat change as it is the sediment left in the system that contributes to morphology.

The ultimate stable scour depth is the potential depth of sediment storage depletion used as a decision parameter for deciding if either scour potential or storage potential exists. This is because its position in relation to the scour depth corresponding to the sediment available defines availability or none availability of scour potential. The scour depth will

be considered in the construction of the model to begin from the sediment storage surface before the arrival of the current discrete discharge. The top of the obstruction unit defining the maximum possible surface of sediment storage will be assumed to be zero ($H_{fullCap}=0$) and the increasing direction of the scour depth will be assumed downwards. This means that erosion will occur downwards towards the ultimate stable scour depth and deposition will occur upwards towards the ultimate stable state of storage. In logical terms, if the state of sediment storage depletion before the current time step is less than the ultimate stable scour depth for the current discrete discharge, there will be scour potential (Fig.3.2).

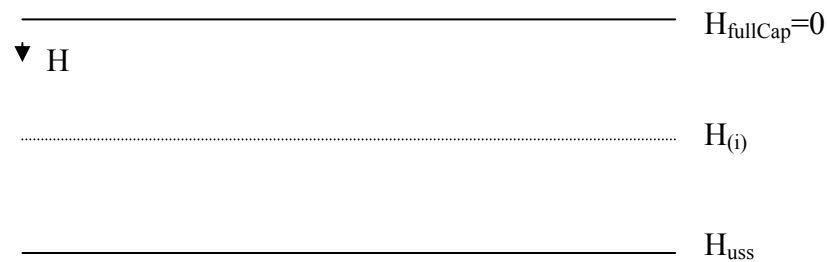


Figure 3.2: Scour potential (H_{uss}) is greater than the actual scour depth ($H_{(i)}$).

In Figs. 3.2 and 3.3:

$H_{fullCap}$ is the scour depth coinciding with the full capacity of the storage unit (m);

▼ H indicates that the positive direction of the scour depth is downwards; and

Lines represent sediment surfaces in idealized cross-sections

On the other hand, if the ultimate stable scour depth for the current discharge is less than the state of sediment storage depletion before the current time step, there will be no potential to scour the sediment (Fig.3.3). Thus any sediment supply treated as sediment supply depth associated with the storage phase of the current discrete discharge will be deposited towards its ultimate stable scour depth.

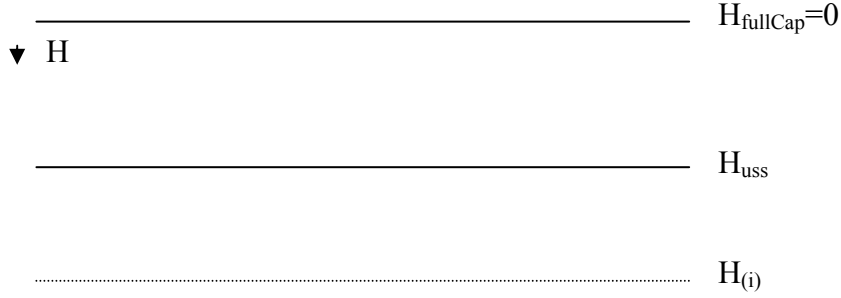


Figure 3.3: The actual scour depth ($H_{(i)}$) is greater than the scour potential (H_{uss}).

The conceptual modelling principle in this thesis can thus be stated that if the scour hole which represents the current state of sediment storage depletion ($H_{(i)}$) is deeper than H_{uss} , no scour potential exists and vice versa. Non availability of scour potential means that the sediment supplied deposits towards H_{uss} for the given discrete discharge and storage unit. Availability of scour potential means erosion occurs towards H_{uss} .

The key model parameters are thus the ultimate stable scour depth (H_{uss}) and the rate of exponential decay (k) with the initial condition described by the sediment available before the entry of the current discrete discharge.

3.10 The translation concept

Sediment storage reaches, channel types and/or morphologic units, which have sediment transport, and sediment storage characteristics and translation reaches characterize bedrock-controlled rivers. Translation reaches transport all the sediment from upstream or from tributaries to downstream storage reaches, channel types and/or morphologic units. Sediment storage reaches, channel types and/or morphologic units and translation reaches will be referred to as sediment storage cells and translation cells respectively in this study. The spatial scale used in modelling of either reaches, channel types or morphologic unit depends on the spatial scale of resolution required of the model results.

Movement of sediment in a series of storage cells e.g. a series of pools (used in the experimental aspect of this study), from upstream to downstream storage cells increases

the volume of sediment available for storage and/or scour in the downstream storage cells. This has the tendency of attenuating (reducing) the scour depth. This is comparable to flood routing in which, the storage effect and increased effective hydraulic resistance reduce (attenuate) the peak flood magnitude and results in delayed attainment of the peak outflow flood magnitude.

The conceptual model proposed (Eq. 3.3) is to be used to model sediment movement in a series of pools. The model computes the storage depletion at the end of each discrete time step in each downstream cell with an assumption of full sediment supply of all the sediment scoured from an immediate upstream cell within the same discrete time step. This means that the volume of sediment scoured in any upstream cell of the model is assumed to be moved to the immediate downstream cell in bulk within the same discrete time step and is considered available for instantaneous erosion or deposition. This is despite the fact that the sediment particles originate from different locations within the cell and thus arrive at the end of the cell at different times. Furthermore, the sediment supplied from upstream, if of different particle sizes and particle densities move at different individual sediment particle velocities. This also ensures different arrival times at the downstream edge of the upstream cell. The model thus assumes that the sediment particles arriving at the downstream edge of the upstream cell before the end of the time step are held there. This assumption makes it possible to route sediment in all the cells at any discrete time steps. The sediment supply and the sediment routing in the downstream cells are therefore instantaneous at the end of the current time step. This is an idealization as the sediment particles that arrive at the downstream edge of the upstream cell at any time within the discrete time step relocate continuously to the immediate downstream cell. Thus there is need to adjust the model time with the lag time to ensure that all the sediment scoured in a given cell moves to the end of that cell and relocates to the immediate downstream cell before sediment routing occurs in the latter cell. The time the sediment takes moving through the translation reach (translation concept) has been hypothesized in this study to be appropriate in accounting for the time lag in sediment routing.

Translation concept would be applicable to all the sediment storage cells provided there is sediment supply from upstream. Sediment supply is sourced either from an upstream external source or from the cells immediately upstream of the downstream routing cells. The need to increase sediment routing period using translation time would therefore be based on the fact that bed load moves at a velocity less than that of water or the sediment storage change routing is done at a model time less than the full sediment supply arrival time. The differences in the sediment translation times would, however, be governed by the differences in the individual particle sediment velocities, which are dependent on the individual sediment particle size and particle density.

The sediment scoured from upstream cells and moved to downstream cells tend to be finer, lighter and faster than those left in the upstream cells. This is because for non-cohesive sediments it is easier to scour fine and light sediments than coarse and dense sediments. This can be explained by Shields' (1936) entrainment function, according to which for the same boundary shear stress or shear velocity, more fine and light sediments than coarse and dense sediments are entrained. This, however, changes as soon as all the fine and light sediments are depleted from the upstream sediment storage units and slow moving coarse and dense sediment particles are scoured and entrained. Thus within each sediment routing or scour time step, there is need to account for variations in sediment transport velocities. This would account for variations in sediment supply velocities to downstream sediment storage units. The translation effect can simulate this behaviour if the translation times or lag times are varied to account for different sediment arrival times due to variations in sediment sizes and densities. Translation effect in the current context theoretically involves the increase in sediment routing time. Translation would account for relatively high sediment supply of fast moving fine and light sediments in the first few hours of scour and relatively low sediment supply of slow moving coarse and dense sediments in the later scour times. Thus net fill is likely to occur at the beginning of the scour time due to high sediment supply and net scour in the later scour time as the sediment supply would be low. Translation can thus be used to simulate net fill and net scour in downstream sediment storage units receiving sediment from upstream sediment storage units.

The integration of the translation concept in the exponential storage depletion function for each discrete discharge is discussed in sub-section 7.4.3. This study views translation as a theoretical concept that accounts for the fact that individual sediment particles with different sediment velocities reach downstream cells at different times. This means that less of the sediment scoured from either the catchment or from the upstream cell would have reached the downstream cell at the end of the model time step if no lag or translation time is included. The amount of sediment transferred to the downstream cell within the model time step is dependent on the sediment velocity, which is dependent on the size and the density of the sediment particles. For example, more of the fine and light sediment supply from upstream cell of relatively high sediment velocity reaches the downstream cell before the end of the model time step that excludes the lag time than relatively slow coarse and dense sediment particles. However, it is important to note that even fine sediment particles moving as bed load and that start from the upstream end of the immediate upstream cell would also take slightly longer to reach the immediate downstream cell than the model time step that excludes the lag time. This is because unlike sediment in suspension they move at a velocity less than that of water. The sediment velocity is therefore important in determining the actual sediment routing time. In addition, the localized shear stress variations due to the local flow fluctuations in response to the local variations in channel roughness and sediment particle orientations may accelerate or decelerate sediment movement and storage. It is thus prudent to introduce the lag or translation time to account for the most probable situation of the scoured sediments taking slightly longer to relocate to the downstream cell than the model time step.

The existence of translation reaches in natural river systems support the introduction of translation as a theoretical concept in the current model. Translation is dependent on the sediment velocity and how long it takes the sediment from an upstream cell or supplied from an upstream catchment to move to the immediate downstream cell.

If there is no sediment supply, there is no lag or delay of scoured sediment occasioned by the arrival of the sediment particles or slugs at different times, and thus there is no need

for inclusion of translation in the storage depletion equation. Translation in the current model would therefore strictly account for the delay in sediment supply arrival times and would therefore only apply when there is sediment supply.

3.11 Active sediment storage

Active sediment storage is the sediment supply dependent dynamic component of sediment storage above sediment storage depletion curve for each discrete discharge when there is no sediment supply.

Sediment supply is an important component of the sediment budget equation. It is hypothesized in this thesis that the sediment supply rate affects the dynamic and ultimate stable storage states. The temporal dynamics of sediment storage would be such that high sediment supply would result in higher state of sediment storage than low sediment supply at any given time for each discrete discharge. Thus for a specific discharge at a given time, high and low sediment supply rates would result in two storage depletion curves. The scour depth associated with high sediment supply would therefore be smaller than that associated with low or no sediment supply (Fig.3.4). These hold provided the initial storage depletion depth (initial scour depth) in the sediment storage unit is the same for the two sediment supply conditions.

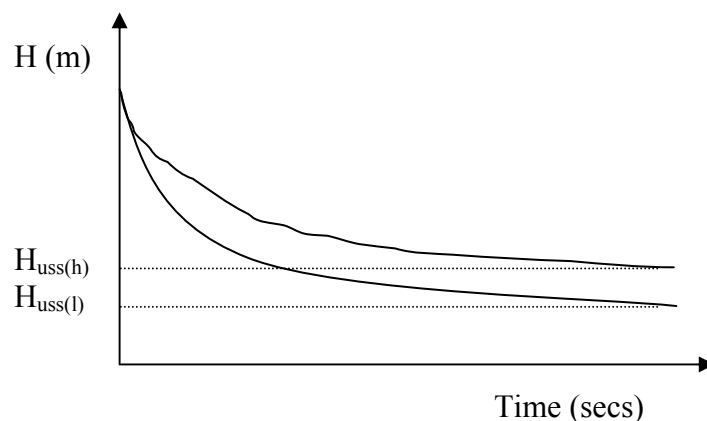


Figure 3.4: Sediment storage depletion curves for the same discharge showing the effect of sediment supply (active sediment storage)

In Fig. (3.4):

$H_{uss(h)}$ – is the ultimate stable storage for a given discrete discharge when there is high sediment supply

$H_{uss(l)}$ – is the ultimate stable storage for a given discrete discharge when there is low or no sediment supply.

The difference between the ultimate stable storage state of a given sediment supply for any discharge and the ultimate stable storage state of the same discharge with no sediment supply gives the ultimate stable active sediment storage. It follows that the active sediment storage at ultimate stable state for the high sediment supply (Fig.3.4) would be given by Eq. (3.6) if $H_{uss(l)}$ is the same as the H_{uss} of the discrete discharge event when there is no sediment supply.

$$\Delta H_{ussA} = H_{uss(h)} - H_{uss(l)} \quad (3.6)$$

where, ΔH_{ussA} is the ultimate active sediment storage for the given sediment supply and discrete discharge.

The dynamic active sediment storage associated with any given sediment supply at any time t would therefore be the difference between the storage on the storage depletion curve for the given sediment supply and discharge and the storage on the storage depletion curve for the same discharge with no supply. Thus the ultimate stable storage and storage depletion curve can be considered as dependent on both the discharge and the sediment supply.

The form of the sediment storage depletion curve for different sediment supplies for the same discharge is expected to follow the same trend (Fig.3.4) except for the difference in magnitudes. This means that the exponential decay parameter (k) is affected by the discharge and not by the sediment supply.

3.12 Summary

A process based numerical method for routing sediment episodically in bedrock-controlled rivers has been proposed and its routing routine briefly explained. The

conceived method is an inverted episodic sediment budgeting approach hypothesized for computing bulk sediment storage changes in storage reaches of bedrock-controlled rivers. The method is dependent on sediment storage characteristics (H_{uss} and storage depletion curve) for discrete discharge events and sediment supply. The ultimate stable scour depth and the storage depletion curve are dependent on flow characteristics particularly discharge magnitude and duration, sediment characteristics and channel characteristics (particularly the channel width). The method works with the translation concept to account for sediment movement in translation reaches and differences in sediment arrival times (or sediment velocity) due to variations in sediment sizes and densities.

The method can be applied to model geomorphic responses in bedrock-controlled rivers in order to predict the ability of such river systems to sustain ecological functions. It emerged that the theory developed for a particular localized system at a given scale of resolution is constrained to that scale. It is therefore imperative that the scales of resolution for developing theories that work for the entire complex system such as a bedrock-controlled river must be generalized as much as possible to widen their domain of application.

CHAPTER FOUR

EXPERIMENTAL MATERIALS AND METHODS

4.1 Preamble

Simple pools have been used in experiments aimed at demonstrating and verifying the use of H_{uss} and storage depletion curve as modelling concepts, although the concepts apply more generally. Five sets of experiments were performed in a laboratory flume. The experiments were aimed at generating data for the following reasons.

- (1) Determining the relationship between the ultimate stable scour depth and discharge for different sediment sizes.
- (2) Determining the storage change with time for different sediment sizes and selected constant discharges (storage depletion curve)
- (3) Establishing the effect of sediment supply on storage depletion curve and ultimate stable scour depth for selected constant discharge (active storage)
- (4) Confirming the working of the modelling concept
- (5) Confirming sediment dynamics model in a series of pools

4.2 Experimental set-up

The experiments were performed in a rectangular laboratory flume with painted steel floor and glass walls. The flume had a width of 380 mm, a height of 660 mm and a length of 15.00 m and a tilting section with a length of 10.40 m. The flume was dropped vertically to a bed slope of 0.00784 to allow sediment movement to occur. The flume was tilted with the aid of an electrically powered jack. This could allow the selection of the slope of the tilting section to desired values.

A simulated rectangular wooden bedrock outcrop geometry (obstruction or weir) of width 380 mm, height 50 mm and thickness 40 mm was introduced at 6.38 m from the upstream location of the tilting section for the single pool experiments and at 2.5 m intervals for the pools in series experiments. This resulted in a triangular sediment storage cross-section (Fig. 4.1). The triangular sediment storage geometry constitutes a pool of sediment. The general

arrangement of the experimental set-up is shown in Fig. 4.2.

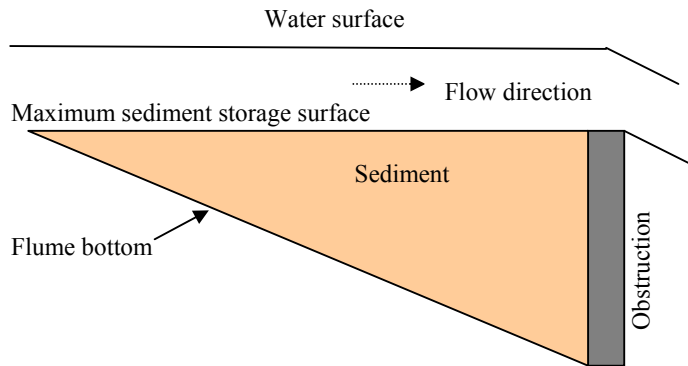


Figure 4.1: Triangular sediment storage cross-section with water surface and flow direction shown

The water was pumped continuously to the constant head reservoir during the experimental runs to maintain the constant head in the reservoir during experiments. The water from the constant head reservoir flowed to the flume entry reservoir by gravity. A gate valve controlled the discharge from the flume entry reservoir into the experimental section of the flume. A water sump immediately downstream of the flume was fitted with a v-notch weir for measurement of discharge. The experimental arrangement is a water recirculating system. It allows water from the sump to be recirculated to the constant head reservoir through the pump by opening a control gate valve.

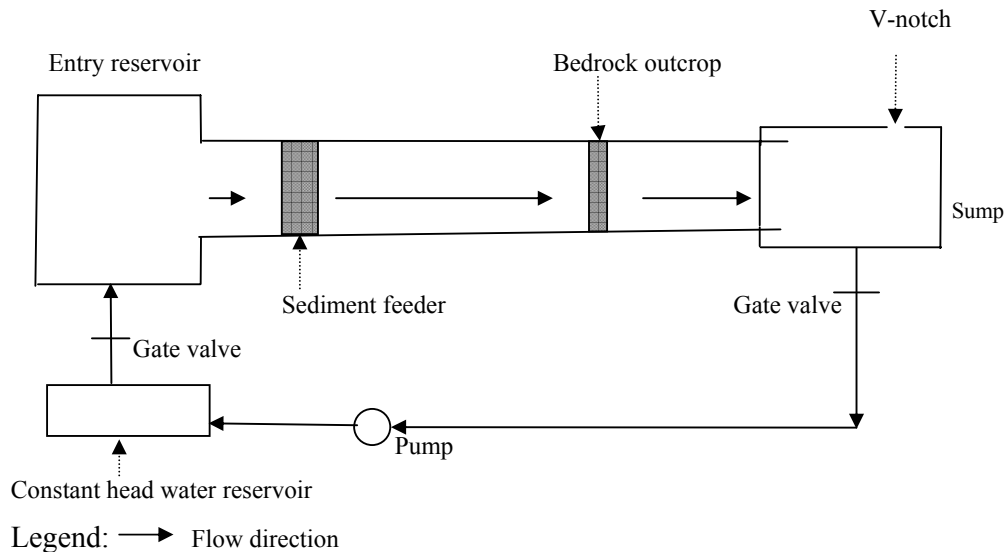


Figure 4.2: Experimental plan arrangement (Not to scale).

A belt feeder with the ability to allow different sediment feed rates was mounted on top of the

flume at the beginning of the tilting section (Fig. 4.3). This allowed feeding of sediment into the flume at approximately constant sediment feed rates for experiments involving the investigation of the effect of sediment supply on storage depletion curve and ultimate stable scour depth.



Figure 4.3: Sediment feeder mounted on the flume

4.3 Choice of representative sediment grains

The choice of representative sediment grains for use in laboratory modelling requires that the transport characteristics of the sediment material and the sediment properties be taken into account. Transport sediment characteristics determine the rate at which sediment moves along the channel bed and in suspension. On the other hand, the sediment properties of importance in influencing sediment transport and channel morphology include particle size, particle density, particle shape, and relative roughness.

Practically all non-cohesive material forming or in transport in beds of natural streams is quartz sand with a specific gravity in the range 2.64 to 2.67 (average 2.65) (Dake, 1983). Because of the larger particle size and the smaller tendency to flocculate, these sands exhibit much more individuality in their movement in water.

River sand and swimming pool filter sand were selected for use in the laboratory experiments. The river sand from visual inspection was sub-rounded to sub-angular while the

filter sand was made up of sub-angular shaped particles. The specific gravities of the river sand and filter sand of 2.63 and 2.62 respectively were experimentally determined. These values on the average deviated from the average specific gravity of quartz sand of 2.65 by 1%, which is an acceptable limit of experimental error. Thus the sand particles selected for use in the experiments were quartz sand.

Sand has been used widely in model experiments in the laboratory. However, models using medium or fine sand often experience difficulty because of the formation of pronounced bed ripples and a coarser, lighter, material may be preferable to their use. To ascertain that the bulk of the sediment material moves as bed load, sand grains in the range coarse sand to very coarse sand (Table 4.1) are proposed for use. The coarseness and the weight of the material is expected to reduce its chances of being sustained in suspension for long by turbulence and instead promote its movement mostly as bed load i.e., through sliding, rolling and occasional jumps (saltation). According to Simons and Simons (1987), ripples do not form, where the median diameter, D_{50} , of the bed material is larger than approximately 0.6 mm (i.e $D_{50} > 0.6$ mm). Therefore, with the use of sand bed material of median diameter larger than 0.6 mm, the formation of the ripples is likely to be suppressed.

Table 4.1: Relevant sediment grade scale guiding choice of sediment sizes (Dake, 1983)

Class Name	Size Range mm
Very Coarse Sand	2.000- 1.000
Coarse Sand	1.000- 0.500
Medium Sand	0.500- 0.250

To avoid the formation of ripples and suppress suspension so that the sediment only moves as bed load, the river sand and the filter sand selected for use in the experiments were of median particle sizes (D_{50}) of 0.775 mm and 1.15 mm respectively. Earlier experiments performed by Harnett (1998) whose results have been adopted in the development of the relationship between ultimate stable scour depth and discharge for the different sediment sizes, used sediment of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm. These fall within the range coarse to very coarse sand (Table 4.1) with the latter falling outside the range provided in the table.

However, the sand of this D_{50} moved as bed load and therefore its results were integrated with the rest of the results.

4.4 Particle size distributions and settling velocities of experimental sediments

4.4.1 Particle size distribution

Grain (particle) size distribution is constituted of the relative proportions of the different grain sizes that make up a given sample mass. The grain size distribution test was performed using the mechanical sieve shaker. A stack of sieves of different aperture sizes varying from the coarsest sieve at the top to the finest sieve at the bottom was placed on the mechanical sieve shaker.

The quantity of sediment retained in each sieve was weighed and the percentage of sediment retained in each sieve calculated as the total sample mass was known. The percentage of sediment passing each sieve was then worked out and plotted against the sieve aperture to determine the particle size distribution curve for each sample mass.

The results for sieve size analyses for the five different sediment size samples used in the five sets of experiments are provided in Figs. 4.4-4.8. The representative particle sizes for describing each sediment sample (D_{50}) given in section 4.3 were read from each of the particle size distribution graphs.

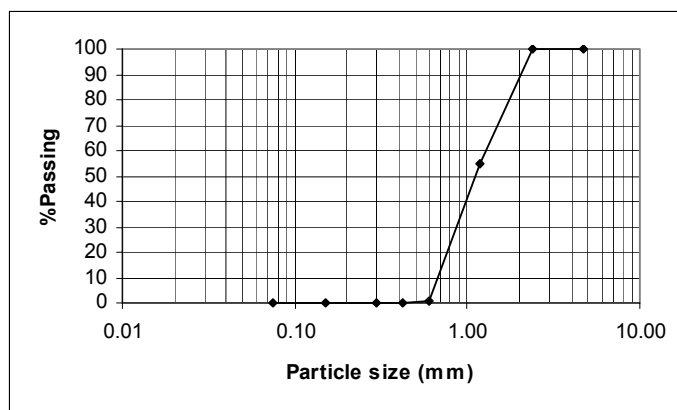


Figure 4.4: Particle size distribution for sand of D_{50} of 1.15 mm (swimming pool filter sand)

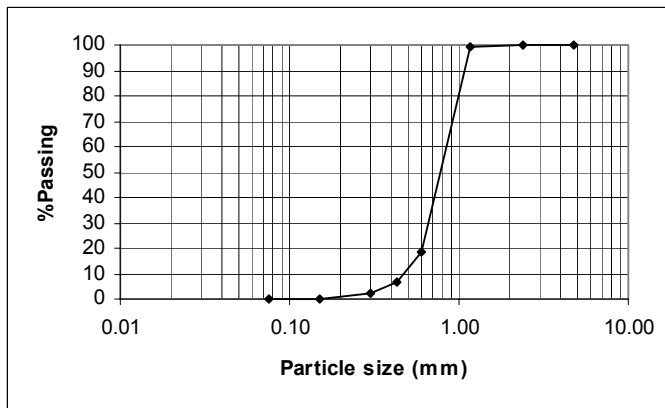


Figure 4.5: Particle size distribution for sand of D_{50} of 0.775 mm (river sand)

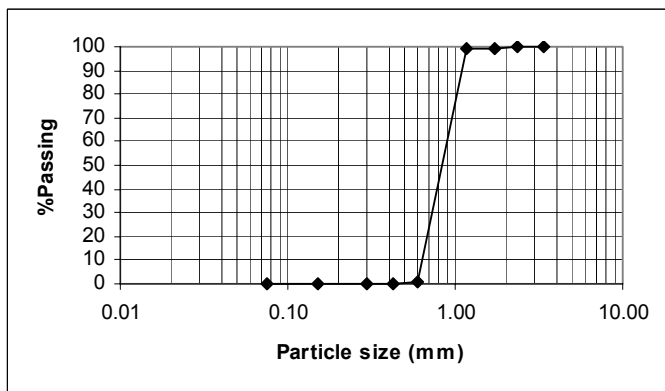


Figure 4.6: Particle size distribution for sand of D_{50} of 0.85 mm (Source: Harnett (1998))

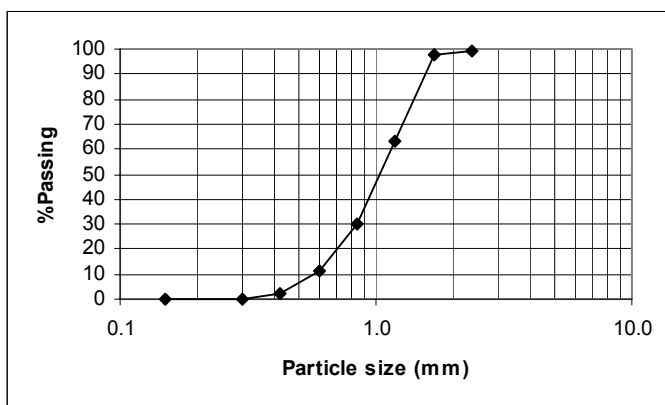


Figure 4.7: Particle size distribution for sand of D_{50} of 1.05 mm (Source: Harnett (1998))

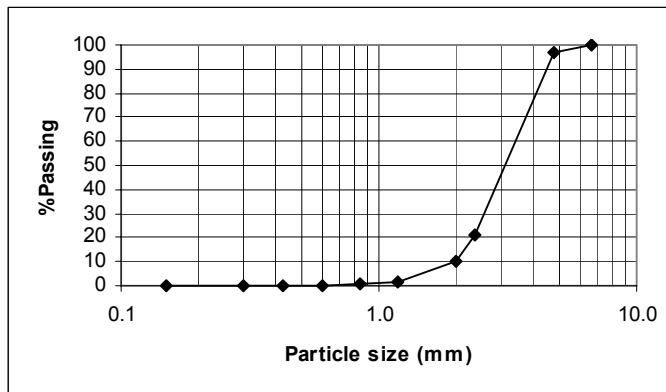


Figure 4.8: Particle size distribution for sand of D_{50} of 3.05 mm (Source: Harnett (1998))

4.4.2 Settling velocity

Settling velocity is the velocity with which the sediment particles fall through the fluid under their own weight. Since settling velocity is dependent on sediment size, Mamak's curve giving the relationship between sediment size and settling velocity for quartz sand of specific gravity 2.65 at water temperature of 20°C (Graf, 1971) was used to estimate the settling velocities for the different sediment samples. The median particle size (D_{50}) read from the particle size distribution curve for each sediment sample was taken as the representative sediment size for each sample. The settling velocities for the five sand samples used in the experiment are provided in Table 4.2.

Table 4.2: Settling velocities of the experimental sediment samples

Median particle size, D_{50} (mm)	Settling velocity, w (mm/sec)
0.775	81
0.850	89
1.050	116
1.150	128
3.050	257

4.5 Experimental procedure and variables measured

Laboratory experiments performed in a pool model are presented in the following sub-sections.

4.5.1 Ultimate stable scour depth

Laboratory experiments aimed at determination of the H_{uss} were performed in a pool filled to a predetermined top surface with sediment of known median sediment size (D_{50}) and settling velocity (w). Five sediment samples of different characteristic particle size distributions and settling velocities were used (Table 4.2).

The pool geometry filled with each sediment size was subjected to a number of steady discharge runs in the range 1-12 litres/sec. Each run scoured the bed from the top surface of the obstruction downward until a stable state of storage (H_{uss}) (Fig. 4.9). Attainment of ultimate stable state of sediment storage was based on observance of stable scour depths, without discernible changes. The ultimate stable scour depth was measured at 50-cm intervals for the first 6 m and at 95-mm intervals for the last 38 cm. The scour depth was measured with a vernier scale mounted on a movable rail gauge (Fig. 4.10).

The experiments by Harnett (1998) approximately achieved the ultimate stable sediment storage state for each constant discharge and sediment size in 35 hours when sediment movement was at its minimum (Tables A1-A15). The ultimate stable scour depth for specific constant discharges within the range given in the preceding paragraph and sediment sizes of 0.775 mm and 1.15 mm (Tables A16-A21) were extracted from the sediment storage depletion data at estimated stable state of sediment storage (sub-section 5.2.1).

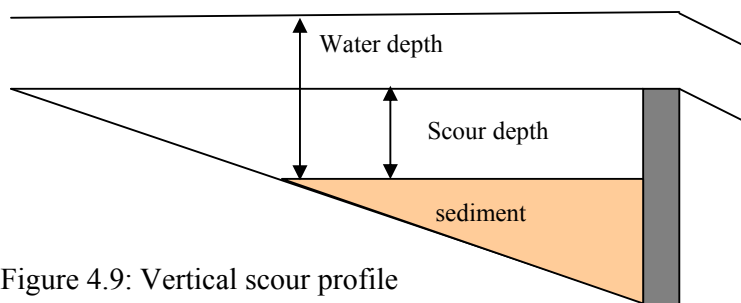


Figure 4.9: Vertical scour profile

4.5.2 Storage depletion curves

Laboratory experiments aimed at developing storage depletion curves and hence determining k (Eq. 3.3) were performed in a pool. Two sediment samples with D_{50} of 0.775 mm and 1.15 mm were used in separate experiments similar to those for H_{uss} except that the scour depth change was monitored with time until H_{uss} was achieved for each constant discharge. A rigorous monitoring schedule was followed at the beginning of each experimental run. The monitoring was done at half hourly intervals for the first two hours followed by one hourly intervals for the next six hours. Monitoring at two hourly intervals before further relaxation of the monitoring schedule as the scour depth changes reduced with time followed this. For the two sediment sizes and the three discharges of 6.9 l/sec, 7.5 l/sec and 8.4 l/sec, experiments were continued for a much longer time, that in some cases exceeded 100 hours to ensure that the ultimate stable sediment storage state was achieved (Tables B1-B72). The frequent disturbance on the sediment surface at the longitudinal scour depth measuring sites by the scour-measuring device may have contributed to increasing the time for attainment of ultimate stable state of sediment storage.



Figure 4.10: Flume section showing a vernier scale mounted on a movable rail gauge

4.5.3 Effect of sediment supply on storage depletion and ultimate stable storage

Four experimental runs aimed at investigating the effect of sediment supply on the storage depletion curves and the ultimate stable scour depths were conducted. The triangular cross-

section upstream of the simulated bedrock outcrop (obstruction) was filled with sediment of particle size 0.775mm up to the surface coinciding with the top of the obstruction in each experimental run (Fig. 4.1). The experiments were conducted in a contracted flume width of 100 mm. The contracted flume width was used because of the limited quantities of sediment available for continuous feeding over the entire long experimental period. A steady discharge of 2.85 litres/sec was applied in each experimental run. The first run acted as a control with no sediment supply while sediment was supplied at steady rates of 1.8 ml/min, 2.5 ml/min and 7.3 ml/min for the next three runs respectively. Each experimental run lasted for between 95-101 hours when a near stable state of sediment storage was achieved. In other words, each experimental run continued until a state of no significant change in measured scour depth change with time was achieved. The sediment supply was then stopped and the steady discharge run continued in each experiment until no further significant erosion took place in the three experimental runs which initially had steady sediment feed rates of 1.8 ml/min, 2.5 ml/min and 7.3 ml/min. The purpose of this was to confirm if the steady discharge would continue to scour sediment along a storage depletion curve to its H_{uss} . This was thus meant to verify the H_{uss} and storage depletion concepts as sediment storage characteristics of steady discharges. The verification of these concepts was enhanced by experiments described in the ensuing paragraph but one.

Reference is made to the experiments, which initially had sediment feed rates of 1.8 ml/min, 2.5 ml/min and 7.3 ml/min and were allowed to continue to scour after the sediment supply was stopped as described in the preceding paragraph. The ultimate stable sediment storage was hypothesized to depend on sediment supply rates for the same steady discharge. The continuation of the steady discharge run after stopping the sediment supply in the three cases was therefore aimed at inferring the uniqueness of H_{uss} for each discrete discharge regardless of the initial sediment storage condition in the channel.

4.5.4 Sediment storage changes with time associated with a series of steady discharges

Two runs of model confirmation experiments aimed at verifying that each steady discharge routes sediment along its storage depletion curve towards its ultimate stable state were performed with and without steady sediment supply. The second purpose was to investigate if the H_{uss} and storage depletion curves derived at the full flume width are applicable at a

different flume width.

A series of steady discharges each of specific finite duration were used in experiments aimed at validating the sediment routing logic associated with discrete discharge events. The sediment routing logic is based on the comparison of H_{uss} and the amount of sediment available in the storage unit (see section 3.9 and section 6.4). A steady discharge of 3.3 l/s lasting for 7 hours 35 minutes was preceded and followed by steady discharges of 1.73 l/s with the former lasting for 5 hours 5 minutes and the latter lasting for 5 hours (Fig. 4.11). No sediment supply was used in this experimental run. In the second experimental run, a steady discharge of 3.3 l/s lasting for 7 hours 20 minutes was preceded and followed by steady discharges of 1.73 l/s, each lasting for 5 hours 56 minutes and 21 hours 15 minutes respectively (Fig. 4.12). In the latter experimental run, the sediment was supplied at a steady sediment supply rate of 1.8 ml/min until the end of the steady discharge of 3.3 l/s. Thus there was no sediment supply when the flow was ultimately restored to a steady discharge rate of 1.73 l/s. The experimental investigation was conducted in a constricted flume width of 100 mm with the full length up to the obstruction of 6.38 m initially filled with sediment of particle size D_{50} of 0.775 mm to a predetermined top surface (Fig. 4.1). The scour depth change with time was monitored for a shorter time than the ultimate scour time for each discharge.

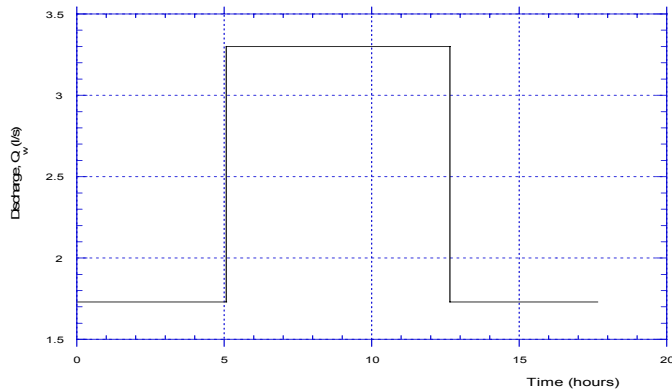


Fig. 4.11: Stepped discharge hydrograph used with no sediment supply

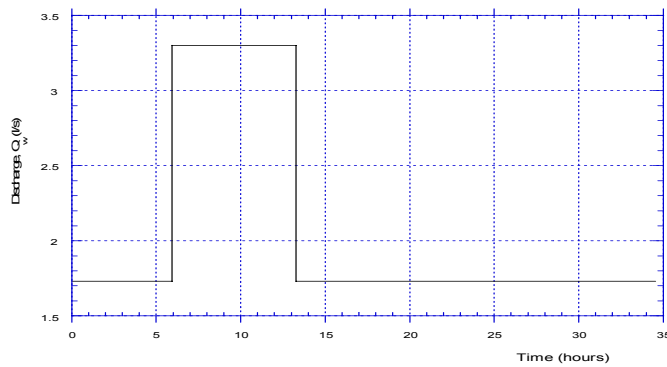


Fig. 4.12: Stepped discharge hydrograph used with sediment supply of 1.8 ml/min applied up to the end of the discharge of 3.3 l/s

4.5.5 Sediment storage changes with time in three pools in series

Laboratory experiments aimed at investigating sediment dynamics in a series of pools so as to confirm the working of the sediment routing logic for a series of pools were performed. The experimental conditions were exactly the same as those of storage depletion curves except each of the three pools was of length 2.5 m. Thus there were three rectangular obstructions each placed 2.5 m apart. Sediment of median particle sizes D_{50} of 0.775 mm and 1.15 mm were used in two separate experimental runs. The first pool was filled with sediment to a predetermined full capacity. The second and the third pools were filled with sediment to approximately four-fifth of the full capacity. The effect of a steady discharge of 11.1 l/sec on sediment storage change with time was monitored for each of the three pools in series until the attainment of H_{uss} in a similar temporal monitoring schedule as storage depletion curves.

The vertical profile of the three pools in series either fully (pool 1) or partly (pools 2 and 3) filled with sediment before the start of each experimental run is shown in Fig. 4.13.

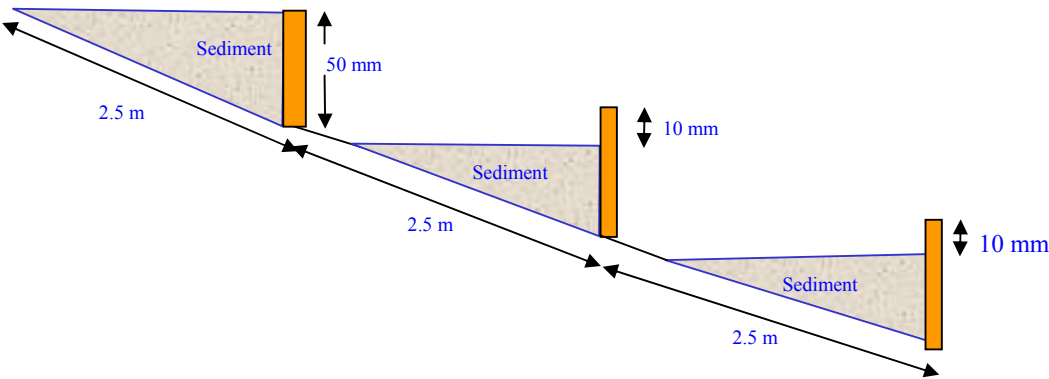


Figure 4.13: The vertical profile of the three pools either fully or partly filled with sediment at the onset of each experimental run

The summary of all the experiments including conditions for which they were tested and the purpose of the tests are provided in Table 4.3.

Table 4.3: List of experiments, conditions tested and purpose

Experiment number	Steady Discharge Q_w (l/s)	Sediment size, D_{50} (mm)	Number of pools	Initial sediment filled volume of the pool	Sediment supply rate (ml/min)	Width of each pool (mm)	Length of each pool (m)	Purpose
1	3.50	0.85	1	Full	0.00	380	6.38	H_{uss}
2	5.00	0.85	1	Full	0.00	380	6.38	H_{uss}
3	7.50	0.85	1	Full	0.00	380	6.38	H_{uss}
4	8.50	0.85	1	Full	0.00	380	6.38	H_{uss}
5	10.00	0.85	1	Full	0.00	380	6.38	H_{uss}
6	3.50	1.05	1	Full	0.00	380	6.38	H_{uss}
7	5.00	1.05	1	Full	0.00	380	6.38	H_{uss}
8	7.50	1.05	1	Full	0.00	380	6.38	H_{uss}
9	8.50	1.05	1	Full	0.00	380	6.38	H_{uss}
10	10.00	1.05	1	Full	0.00	380	6.38	H_{uss}
11	3.50	3.05	1	Full	0.00	380	6.38	H_{uss}
12	5.00	3.05	1	Full	0.00	380	6.38	H_{uss}
13	7.50	3.05	1	Full	0.00	380	6.38	H_{uss}
14	8.50	3.05	1	Full	0.00	380	6.38	H_{uss}
15	10.00	3.05	1	Full	0.00	380	6.38	H_{uss}
16	6.90	0.775	1	Full	0.00	380	6.38	H_{uss}
17	7.50	0.775	1	Full	0.00	380	6.38	H_{uss} and storage depletion curve
18	8.40	0.775	1	Full	0.00	380	6.38	H_{uss} and storage depletion curve
19	6.90	1.15	1	Full	0.00	380	6.38	H_{uss} and storage depletion curve
20	7.50	1.15	1	Full	0.00	380	6.38	H_{uss} and storage depletion curve
21	8.40	1.15	1	Full	0.00	380	6.38	H_{uss} and storage depletion curve
22	2.85	0.775	1	Full	0.00	100	6.38	- Control experiment for effect of Q_{sin} on H_{uss} and storage depletion curve - Effect of b on H_{uss} and storage depletion curve
23	2.85	0.775	1	Full	1.80	100	6.38	- Effect of Q_{sin} on H_{uss} and storage depletion curve - Confirmation of the uniqueness of H_{uss} for each steady discharge and its non-dependence on H_{init}
24	2.85	0.775	1	Full	2.50	100	6.38	- Effect of Q_{sin} on H_{uss} and storage depletion curve - Confirmation of the uniqueness of H_{uss} for each steady discharge and its non-dependence on H_{init}
25	2.85	0.775	1	Full	7.30	100	6.38	- Effect of Q_{sin} on H_{uss} and storage depletion curve - Confirmation of the uniqueness of H_{uss} for each steady discharge and its non-dependence on H_{init}
26	3.3 preceded and followed by 1.73	0.775	1	Full	0.00	100	6.38	Verification of the sediment routing logic or verification of the working of the modelling concept
27	3.3 preceded and followed by 1.73	0.775	1	Full	1.80	100	6.38	Verification of the sediment routing logic when there is sediment supply
28	11.1	0.775	3	Pool 1 full and pools 2 and 3 partly filled	0.00	380	2.5 (For each pool)	Confirmation of the working of the routing logic for a series of pools with sediment of $D_{50}=0.775$ mm
29	11.1	1.15	3	Pool 1 full and pools 2 and 3 partly filled	0.00	380	2.5 (For each pool)	Confirmation of the working of the routing logic for a series of pools with sediment of $D_{50}=1.15$ mm

4.6 Practical limitations

The scour depth changes with time were measured at discrete cross-sections across the longitudinal profile of the pool. This was applicable to storage depletion experiments, H_{uss} and storage depletion dependence on sediment supply experiments and model confirmation experiments. The pointer gauge used in the scour depth measurement had its sharp pointed tip in contact with the top surface of the sediment on monitoring scour depth change with time. The disturbed sediment surface could contribute to overestimation of the scour depth. However, this may not have contributed a serious error as the discharges used were strong enough and moved sediment to refill the disturbed sediment surfaces instantly. Given that scour depth change with time had to be monitored over several time intervals, the cumulative effect of the disturbance could lead to a somehow exaggerated value of the H_{uss} .

The discrete values of H_{uss} and scour depth measured at different time intervals and integrated over all the longitudinal profiles would not be as accurate as those that are based on use of a continuous longitudinal scour depth profiler. The change in scour depth with time was also at the mm scale and therefore any small disturbance on the sediment surface to the same scale could affect the accuracy of the results.

The scour depths at the monitoring cross-sections measured at the centre of the flume at each time step were likely to be overestimated unlike if a continuous scour depth profiler integrated them across the entire transverse cross-section. This could be attributed to the side/wall effect/resistance that reduces the shear stress (non-uniform shear stress distribution) and contributes to less erosion in the immediate vicinity of the wall. This might have caused non-uniform sediment distribution across the measuring cross-sections. Thus the scour depth near the wall was likely to be less than that at the centre. However, due to the small width of the flume, the wall effect may have been nearly uniform as it could be felt nearly equally across the whole transverse cross-section.

The variations in shear stress distribution across the longitudinal profiles were also likely to be different at different times, as there could have been tendencies to concentrate shear stress in certain locations and not others. This could have affected sediment distributions across the longitudinal profiles at different times. Thus the longitudinal scour depth measuring points

would at times undergo net scour, net fill or a balance of the two.

Non-uniform packing of sediment grains in the longitudinal measuring cross-sections of the channel could also influence the scour depth. The significant length of time required to manually measure the scour depth over all the longitudinal profiles may have led to inaccurate results. There was almost an overlap in monitoring times especially for short time monitoring intervals at the beginning of the experiments.

For experiments involving sediment supply, the belt sediment feed could fluctuate due to non-uniform packing of sediments and weight of sediments exerted on the feeder.

The ultimate stable state of sediment storage may not have been an exact state of stable storage as longitudinal and transverse cross-sections across the entire flume length may not have attained minimum stream power. Some sections may have had concentrated stream power and therefore experienced minimal movement of sediment particles. However, this may not have been significant, as the particles would be moving to locations with minimal stream power and therefore just redistribute in the channel. A few sediment particles around the obstruction, however, continued to be eroded due to flow accelerations and decelerations around the weir. Thus, some minimal sediment movement continued to be observed at or near the ultimate stable state of sediment storage. Thus some experiments may have been stopped either slightly earlier or later than the theoretical exact ultimate stable state of sediment storage.

Long experimental monitoring times (continuous in terms of days) made it difficult to continue following a rigorous monitoring schedule at short time intervals.

4.7 Summary

This chapter presented the rationale for the choice of suitable experimental sediment material with the ability to move as bed load. The sediments of different particle size distribution have been described in terms of their median particle size (D_{50}) and settling velocities.

The procedures for experimental determination of H_{uss} , storage depletion curves and

influence of sediment supply on H_{uss} and storage depletion curves have been described. Confirmation experiments aimed at validating the episodic sediment routing concept and confirming the model's ability to route sediment in a series of sediment storage units (pools in this case) have also been described.

The key variable monitored in all the experiments over discrete longitudinal cross-sections of the channel was the scour depth change with time or at ultimate stable state of sediment storage.

CHAPTER FIVE

PRESENTATION, INTERPRETATION AND SIGNIFICANCE OF EXPERIMENTAL RESULTS

5.1 Preamble

This chapter presents all the results for experiments performed to generate data for reasons explained in section 4.1. The representation of sediment storage changes associated with each discrete discharge lasting for infinite time in terms of storage depletion curve and H_{uss} is demonstrated in this chapter. The dependence of sediment storage change measured in terms of the scour depth on physical variables and flow conditions that influence sediment transport in bedrock-controlled rivers are determined in this chapter.

The dependence of measured scour depth on discharge, critical depth of flow and settling velocity (and/or representative sediment size (D_{50})) is investigated to establish the influence of these variables on sediment storage change in bedrock-controlled rivers. The ultimate aim is to determine the appropriateness of these variables in making sediment scour parameters of H_{uss} and storage depletion curve for each discrete discharge dimensionless. Critical flow depth is considered as an important independent variable as it describes the flow condition by integrating discharge and the channel width (morphology parameter). Discharge and channel morphology are both important factors controlling sediment scour or storage in bedrock-controlled rivers.

Experimental results on sediment storage change with time with and without sediment supply at a different channel width are used to establish:

- (i) the existence of sediment supply rate dependent dynamic (active) sediment storage above the storage depletion curve and H_{uss} for each discharge at corresponding scour or storage times,
- (ii) the dependence of storage depletion curve and H_{uss} on channel morphology (channel morphology is represented by channel width in this study), and
- (iii) to show the uniqueness of H_{uss} for each discharge and non-dependence of H_{uss} for each discharge on initial sediment storage condition (H_{init} in this study)

Experimental results with steady discharges that last for some time and either increase or decrease to another steady discharge lasting for some time is presented to experimentally validate the concepts of storage depletion curve and H_{uss} for each discharge. The aim is to show that regardless of the initial sediment storage condition (initial scour depth), scour occurs along a storage depletion curve for each steady discharge until its specific H_{uss} is achieved.

Experimental results for three pools in series in a laboratory pools model with steady discharges and different sediment sizes are presented and discussed to show how the sequencing of pools affects the sediment storage changes. The ultimate aim is to use these experimental results in verification of a sediment dynamics budget model of a series of pools built on the basis of H_{uss} and storage depletion curve concepts of discrete discharges. This is considered as a prototype model appropriate for modelling sediment dynamics in bedrock-controlled rivers.

5.2 Ultimate stable scour depth

5.2.1 Experimental results

The ultimate stable scour depth at scour depth measuring sites for each constant discharge and sediment sample of specific representative size was computed from the difference between the measured gauge heights at the beginning of the H_{uss} experiments and that corresponding to the ultimate stable scour state (Tables A1-A21). The experimental results used in the computation of H_{uss} included those of Harnett (1998)

(Tables A1-A15). The ultimate stable scour depth for each constant discharge and sediment sample of specific D_{50} was determined by integrating the discrete scour depth values computed at each longitudinal scour depth-monitoring site over the entire longitudinal profile. Thus the H_{uss} corresponding to each discrete discharge and sediment sample of specific D_{50} (Table 5.1) is an average value integrated over the entire longitudinal profile of the pool. The H_{uss} for each constant discharge in Tables A1-A21 is presented in the format in which they were computed in Microsoft excel spreadsheet.

Table 5.1: Experimental H_{uss} for constant discharges or critical depths of flow for full experimental flume width and sediment samples each of specific D_{50} with corresponding settling velocities (experiments with sediment samples of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm were performed by Harnett (1998))

Experiment number	Discharge, Q_w (Litres/sec)	Critical flow depth, y_c (mm)	Median grain Size, D_{50} (mm)	Settling velocity, w (mm/sec)	Ultimate stable scour depth, H_{uss} (mm)
1	3.5	20.5	0.85	89	5.6
2	5.0	26.0	0.85	89	8.3
3	7.5	34.1	0.85	89	12.3
4	8.5	37.1	0.85	89	15.6
5	10.0	41.3	0.85	89	19.0
6	3.5	20.5	1.05	116	3.6
7	5.0	26.0	1.05	116	7.1
8	7.5	34.1	1.05	116	12.7
9	8.5	37.1	1.05	116	13.6
10	10.0	41.3	1.05	116	17.5
11	3.5	20.5	3.05	257	0.0
12	5.0	26.0	3.05	257	0.1
13	7.5	34.1	3.05	257	2.8
14	8.5	37.1	3.05	257	3.7
15	10.0	41.3	3.05	257	4.6
16	6.9	32.3	0.775	81	13.6
17	7.5	34.1	0.775	81	19.9
18	8.4	36.8	0.775	81	21.9
19	6.9	32.3	1.15	128	12.7
20	7.5	34.1	1.15	128	16.9
21	8.4	36.8	1.15	128	20.4

The ultimate stable scour depth for constant discharges of 6.9 litres/sec, 7.5 litres/sec and 8.4 litres/sec and the two sediment samples of D_{50} of 0.775 mm and 1.15 mm (Table 5.1)

were estimated from the integrated scour depths of storage depletion curves (Tables B1-B72; Fig. 5.1). This was based on the time when minimal scour depth change with time was achieved. The time for achieving the ultimate stable scour depth for different discharges and different sediment sizes was in the range 29-121 hours. Many factors control how long it takes to achieve the ultimate stable state of sediment storage. Some of such factors include discharge magnitude, sediment size, particle packing and/or grain orientation, and the frequency of disturbance of the sediment surface by the scour-measuring device.

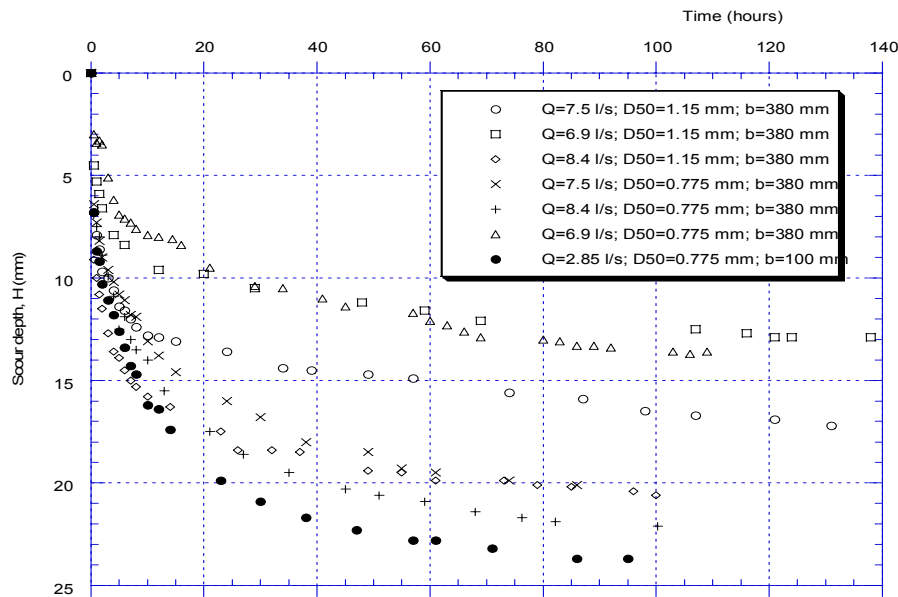


Figure 5.1: Experimentally measured storage depletion curves

The storage depletion scour depths at scour depth measuring sites for each constant discharge and sediment sample of specific D_{50} at each monitoring time were computed from the difference between the measured gauge heights at the beginning of the experiment and those corresponding to the scour time (Tables B1-B72). The gauge height at the beginning is the gauge height measured before erosion begins and scour time is the time elapsed since the beginning of the experiment. This means the scour time corresponds to sediment storage depletion time since the beginning of the experiment.

The scour depth at each current time plotted in Fig. 5.1 was then determined by integrating the discrete scour depth values computed at each longitudinal scour depth-monitoring site over the entire longitudinal profile. These integrated scour depths are presented as average scour depths under each elapsed time since the beginning of the experiment in Tables B1-B72. The storage depletion scour depths in Tables B1-B72 for each constant discharge and scour time are presented in the format computed in the Microsoft excel spreadsheet.

The scour depth changes with time are shown increasing downwards from the full level of the pool (scour depth, $H=0$) (Fig. 5.1). The downward direction is the positive direction of scour in conformity with the format presented in section 3.9.

5.2.2 Ultimate stable scour depth-discharge relationship

The dependence of H_{uss} on discharge for sediment samples of different D_{50} is provided in Fig. 5.2. The ultimate stable scour depth for sediment of particular D_{50} is shown to be approximately linearly dependent on discharge. The experimental results show that H_{uss} increases with discharge magnitude. The steep slope exhibited in the linear relationship between H_{uss} and discharge for sediment samples of D_{50} of 0.775 mm and 1.15 mm (Fig. 5.2) may possibly have been contributed by the experimental conditions.

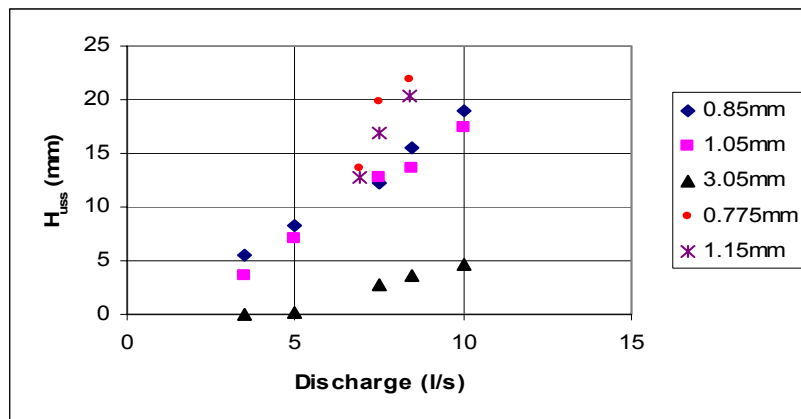


Figure 5.2: Ultimate stable scour depth – discharge relationship for sediment of different particle sizes (experiments with sediment samples of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm were performed by Harnett (1998))

The ultimate stable scour depths associated with the sediment samples of D_{50} of 0.775 mm and D_{50} of 1.15 mm were derived from the storage depletion curves, which involved frequent measurement of scour depth change with time for each constant discharge. The over estimation of H_{uss} may therefore be explained in terms of the cumulative error in scour depth due to the disturbance of the sediment surface on measuring the scour depth change over each time interval. Harnett's (1998) experiments with sediment samples of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm may not have the same error as the scour depth was only measured once at ultimate stable state for each constant discharge and sediment sample of specific D_{50} .

5.2.3 Ultimate stable scour depth-settling velocity relationship

The relationship between the H_{uss} and settling velocity of sediment particles used in the experiments was investigated by plotting H_{uss} against the settling velocities provided in Table 5.1. The plot shows H_{uss} generally reducing with increase in settling velocity except for the sediment sample of D_{50} of 1.15 mm and settling velocity of 128 mm/sec (Fig. 5.3). The exception observed with the sediment sample of settling velocity 128 mm/sec could possibly be attributed to cumulative errors due to frequent disturbance on the sediment surface by the measuring device as explained in sub-section 5.2.2.

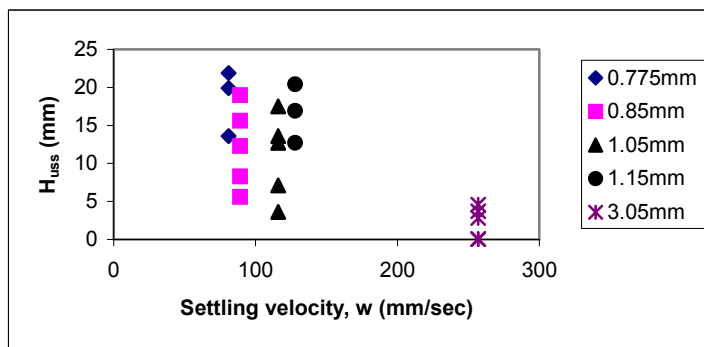


Figure 5.3: Ultimate stable scour depth – settling velocity relationship (experiments with sediment samples of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm were performed by Harnett (1998))

5.2.4 Ultimate stable scour depth-critical flow depth relationship

The dependence of H_{uss} on critical flow depth (Fig. 5.4) is exactly the same as that of H_{uss} on discharges (Fig. 5.2). This is because critical depth of flow (y_c) is itself dependent on discharge and the width of flow. This makes y_c a much more integrated parameter as it includes the effect of the morphology through channel width. Furthermore, it also describes the flow condition (critical or near critical flow) characteristic of bedrock-controlled rivers (Miller and Cluer, 1998). The critical depth of flow was computed from Eq. (5.1) for a rectangular channel.

$$y_c = \sqrt[3]{\frac{q^2}{g}} \quad (5.1)$$

where, y_c is the critical depth of flow (m); $q = Q_w/b$ is the discharge per unit width (m^2/s); Q_w is the discharge (m^3/s); b is the channel width (m); and, g is the gravitational acceleration (m/s^2).

Width is a morphological parameter of interest in the development of dimensionless forms of H_{uss} and storage depletion curve as will be demonstrated in sections 6.3 and 6.4. If the width is a constant as is the case currently then the effect of y_c is the same as that of discharge as is demonstrated in Figs. 5.2 and 5.4.

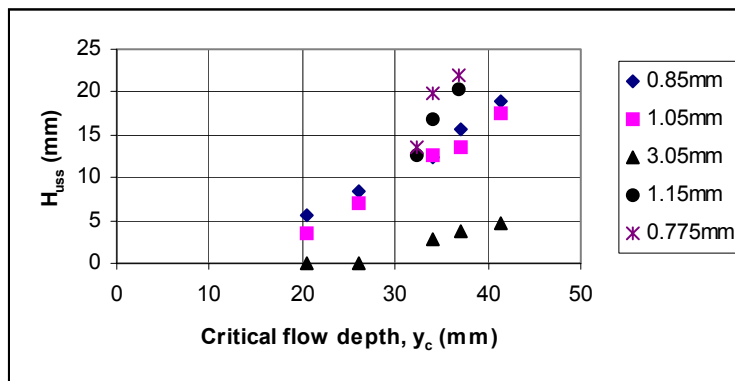


Figure 5.4: Ultimate stable scour depth – critical flow depth relationship (experiments with sediment samples of D_{50} of 0.85 mm, 1.05 mm and 3.05 mm were performed by Harnett (1998))

5.3 Storage depletion curves

Sediment storage change with time as erosion occurs can be represented graphically by a curve that shows storage depletion with time. Such a curve is referred to as storage depletion curve. Examples of storage depletion curves are provided in Fig. 5.1. The scour depths are shown increasing downwards from the top level of the pool ($H=0$) to the positive downward direction of scour. The variation of sediment scour depth with time data from which integrated scour depths for generating the storage depletion curves were derived are presented in Tables B1-B72. The storage depletion curves show a drastic change in sediment depletion (rapid increase in scour depth) with time though at a reducing rate within the first 10-12 hours of the experiment. Afterwards the rate of increase in storage depletion (scour depth change) with time continued to reduce gradually until the H_{uss} was attained for each sediment sample and constant discharge.

Storage depletion (scour depth change) at any given time increases with increase in discharge for each sediment sample of specific D_{50} (Fig. 5.1). This means that storage depletion is directly dependent on discharge magnitude. Thus discharge magnitude is an important variable influencing sediment storage depletion.

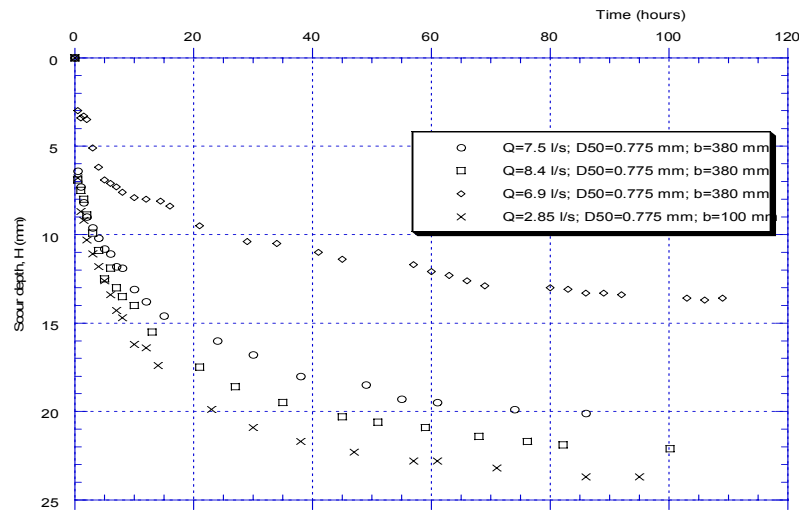


Figure 5.5: Storage depletion curves for sediment of same D_{50} and different flume widths

The control experiment involving no sediment feed for experiments aimed at investigating the effect of sediment supply on storage depletion and ultimate stable state in a contracted flume width of 100 mm using a steady discharge of 2.85 litres/sec (active storage experiments) refers (section 4.5). The storage depletion curve for the latter experiment and those with the full flume width (380 mm) under the three discharges of 6.9 litres/sec, 7.5 litres/sec and 8.4 litres/sec each done with the same representative sediment size (D_{50}) of 0.775 mm were compared (Fig. 5.5). Though the experiment on the contracted flume width (100-mm) was done with the lowest discharge (2.85 litres/sec), the scour depth at any given time (Tables C1-C11) exceeded those of the three higher discharges done at the full flume width. The other experimental conditions were the same for the two sets of experiments. The results show that the scour depth is inversely related to the channel width. This is because the smaller the channel width the bigger the scour depth. This corresponds to the expectation, as the lowest discharge is the highest unit width discharge (Table 5.2). Thus the channel width is an important variable influencing sediment storage depletion.

Tab 5.2: Unit width discharges used in storage depletion experiments

Discharge, Q (m^3/s)	Width, b (m)	Unit width discharge, q (m^2/s)
0.00285	0.10	0.0285
0.0069	0.38	0.0182
0.0075	0.38	0.0197
0.0084	0.38	0.0221

The scour depth change (storage depletion) at any given time for the same discharge runs with sediment samples of D_{50} of 0.775 mm and 1.15 mm is generally bigger for finer sediment samples ($D_{50}=0.775$ mm) than coarser sediment samples ($D_{50}=1.15$ mm) (Fig. 5.1). The comparison involved two storage depletion curves for a constant discharge e.g. of 7.5 litres/sec used in two different experiments each with a different sediment sample of either D_{50} of 0.775 mm or D_{50} of 1.15 mm. The exception was observed with the lowest discharge run of 6.9 litres/sec in which the storage depletion curve for sediment

samples of specific D_{50} of 0.775 mm (fine sediment) was not distinctly greater than that of the coarse sediment sample of D_{50} of 1.15 mm. In this case the experimental results show the coarser sediment sample either scouring more or the same or slightly less than the finer sediment sample for the same constant discharge. The possible explanation for this is provided in the ensuing paragraph.

The fine sediment sample (D_{50} = 0.775 mm) was from a natural river environment and had a wide range of sediment sizes both fine and coarse (Fig. 4.5). This was unlike the coarse sediment (D_{50} = 1.15 mm) which was a graded swimming pool filter sand with a narrow range of sediment sizes (only coarse) (Fig. 4.4). This means that there was likely to be a problem associated with heterogeneous sediment sizes. Fine sediment particles in the bed, as reported in Wu et al. (2000), were more likely to be sheltered (hidden) by coarse particles. Significant transport of fine bed material hiding in the armour only occurs at high flows capable of mobilizing the armour (Lisle and Hilton, 1999; Parker, 1978; Parker and Klingeman, 1982; Andrews, 1984). This means that at low flows, the armour effect was likely to dominate and make the coarse and fine sediment matrix to display nearly similar behaviour as coarse sediments. The armour could therefore have been relatively difficult to scour and transport unless the velocity was high (i.e. high discharge for the same cross-sectional area).

The disturbance by the scour-measuring device on the top surface of the coarser sediment particles in the flume was more pronounced at low flows than that of finer sediment particles. This was because at low flows the sediment scour velocity was very low and was not sufficient to immediately redistribute the disturbed sediment particles back to the disturbed scour hole/surface. This may have resulted in a significant cumulative error in scour depth. Since the deviations in the scour depth between the storage depletion curves for finer (D_{50} = 0.775 mm) and coarser (D_{50} = 1.15 mm) sediments are in general more pronounced at later times (>10 hours) this latter possibility of explaining the exception seems to have been the major contributing factor. This is because the integrated scour depth values across all the measuring cross sections along the longitudinal profile before the current time cumulatively provide the current integrated (plotted) scour depth. This

means that errors in scour depth measurements that might have appeared earlier in the experimental time steps plus the current ones are cumulatively integrated in the present scour depth.

Shields (1936) diagram may be used to explain why the scour depth in fine sediment particles mostly exceeded that in coarse sediment particles at any time along the storage depletion curve for the same discharge. This can be done on the basis of the Shields parameter (entrainment function) for flows of similar characteristics or the same boundary shear stress. From the Shields parameter, for the same shear force (τ) or shear velocity (u_*), lighter and smaller sediment particles are likely to have higher entrainment function compared with heavier and larger sediment particles. Thus for the same τ or u_* more fine sediments are likely to be scoured than coarse sediments. This can possibly explain the scouring of more fine sediments ($D_{50}=0.775$ mm) than coarse sediments ($D_{50}=1.15$ mm) generally observed along the storage depletion curve (Fig. 5.1) for the same discharges. It is important to note that the variations in scour depth may most likely be explained in terms of the sediment sizes as the relatively fine and relatively coarse sediment samples used were of nearly the same specific gravities (section 4.3).

5.4 Effect of sediment supply on ultimate stable storage and storage depletion

The results of experimental investigation of the effect of sediment supply on H_{uss} and storage depletion curve associated with discrete discharge magnitude are presented in Tables C1-C61 and Fig. 5.6. The experimental results were investigated in a single pool upstream of a weir in a contracted flume width of 100 mm, length 6.38-m and initially full of sediment sample with D_{50} of 0.775 mm (see details in section 4.5 and summary in Table 4.3). The results show that for a steady discharge of 2.85 l/s the scour depth at any time t is deeper for no or low sediment supply than high sediment supply (Fig. 5.6). For example the highest sediment feed rate of 7.3 l/s in the experiments had the lowest scour depths at all times compared to the other sediment supply rates (Fig. 5.6). Thus the amount of sediment stored in the channel/pool is dependent on the rate of sediment

supply. The higher the sediment supply rate the more the sediment stored in the channel for a given discharge event.

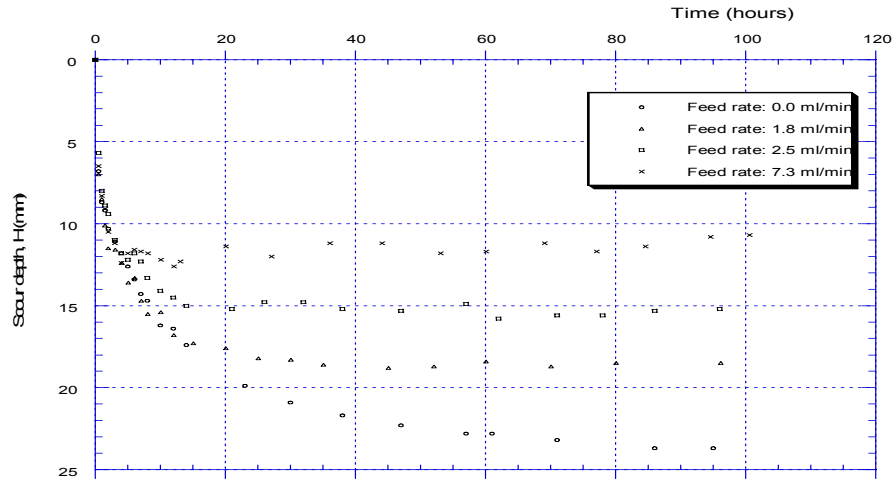


Figure 5.6: Experimentally measured scour depth-time relationships for different sediment feed rates at a constant discharge of 2.85 l/s using sediment with D_{50} of 0.775 mm at a contracted flume width of 100 mm.

The experiments with no sediment supply (Fig. 5.6) was used as a control experiment to give the storage depletion curve and the H_{uss} for the constant discharge ($Q_w=2.85$ l/s) used in the experiment at the contracted flume width of 100 mm. Any sediment storage above the storage depletion curve with no sediment supply at any time t for a given steady discharge provides the dynamic sediment storage (active sediment storage) associated with a specific sediment supply rate (section 3.10). The magnitude of active sediment storage is therefore dependent on the sediment supply rate for the same discharge and the same initial sediment storage in a sediment storage channel of a particular geometry. Since high sediment supply rate results in small scour depth (Fig. 5.6), it follows that high sediment supply rate results in high active sediment storage. Similarly, the fact that low sediment supply rate results in big scour depth (Fig. 5.6), means that low sediment supply rate results in low active sediment storage. Thus the magnitude of active sediment storage is directly proportional to the sediment supply rate.

The sediment storage depletion is an indication that though both sediment scour and sediment storage occurs, the pool undergoes net scour with each sediment supply. The active stable sediment storage state with each sediment supply was achieved when sediment input rate was equal to sediment output rate. In other words, there was neither net sediment scour nor net sediment storage (i.e. no change in sediment storage occurred) at active stable sediment storage state.

The slight fluctuations in the successive scour depths with time for each steady sediment feed rate that made previous scour depths in some cases to exceed the latter scour depths might partly have been due to fluctuations in the belt feed rate (belt movement). The packing of the slightly angular sediment particles of heterogeneous particle size range and the weight of the sediment in the sediment hopper (Fig. 4.3) exerted on the belt might have partly contributed to this.

The movement of bed load as waves which was observed in this study particularly when there was sediment supply and has also been reported in a number of field and flume studies including those of Griffiths (1979, 1993), Church and Jones (1982), Meade (1985), Ashworth and Ferguson (1986), Ashmore (1985, 1991), Hoey and Sutherland (1991) among others may also explain the fluctuations in scour depth with time. The higher the sediment supply the more significant is the scour depth fluctuation with time. For example the highest feed rate (7.3 ml/min) shows a consistent general rise in the curve after the initial dip (Fig. 5.6). This as can be confirmed from the studies quoted above confirms high sediment supply as an important cause of sediment movement as bed waves.

The experimental results (Fig. 5.6) have clearly shown that sediment storage change with time for a given steady discharge is dependent on sediment supply. Sediment supply determines the magnitude of active sediment storage (active scour depth in the current study) at any time t and the ultimate stable active storage (active H_{uss} in the current study) for a given sediment supply and steady discharge. The dependence of sediment storage changes with time on sediment supply for any steady discharge is therefore an important

factor that must be accounted for in sediment dynamics model for pools or bedrock-controlled rivers in general.

The relationship between sediment storage change and sediment supply for steady discharges needs to be investigated further in order to develop a predictive relationship between active sediment storage and sediment supply for each steady discharge. This will make it possible to predict the dynamic sediment storage associated with any sediment supply. This will improve on the model proposed for predicting sediment dynamics in bedrock-controlled rivers (section 3.9) as it will include functions for computing both the storage changes associated with steady discharge magnitudes (storage depletion curve) and the active storage associated with sediment supply. This means that the storage depletion curve for a given discharge will model the sediment storage changes along the storage depletion curve with time and if there is sediment supply, the active storage will be computed at each time step and integrated with the storage depletion curve results. It will thus be possible to separate the effect of sediment supply from that of the discharge on sediment dynamics in bedrock-controlled rivers.

5.5 Sediment storage changes with time associated with a series of steady discharges

Experiments performed in a laboratory pool model in which a steady discharge of 1.73 litres/sec was stepped up after 5-6 hours to a steady discharge of 3.3 litres/sec which was finally stepped back after 7-8 hours to 1.73 litres/sec (Fig. 4.12) refers. The experimental conditions are described in section 4.5 and summarized in Table 4.3. The scour depth changes with time are presented in Tables D1-D21.

A bigger steady discharge (3.3 litres/sec) depletes sediment along a steeper storage depletion curve than a smaller steady discharge (1.73 litres/sec) (Fig. 5.7). This is because a bigger discharge has high scour potential compared to a smaller discharge. Thus scour potential is dependent on the discharge magnitude. It is important to note from the experimental results that each steady discharge depletes sediment along its own

storage depletion curve with time regardless of the initial sediment storage before each discharge enters provided there is the potential to scour the sediment.

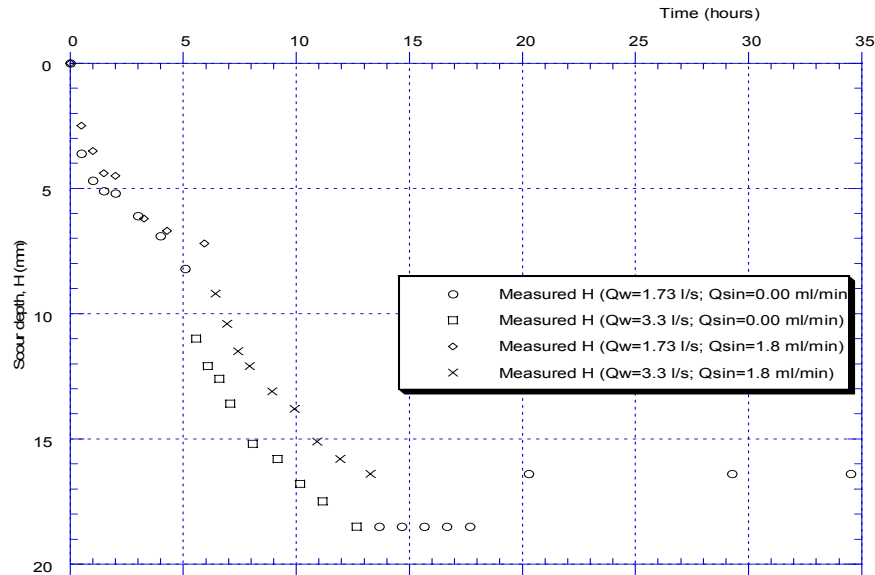


Figure 5.7: Experimentally measured scour depth-time relationship for stepped discharge hydrograph with and without sediment supply.

The scouring of sediment by a smaller discharge (1.73 litres/sec) before and not after a bigger discharge (3.3 litres/sec) had scoured the pool deeper shows that the ability of a given discharge magnitude to scour sediment from a pool is dependent on the depth of the scour hole. The scour hole gives the depth of sediment depleted from storage. It is therefore an indication of the state of sediment availability in the channel or pool in this study. Thus the experimental results show that the potential to scour or not to scour sediment depends on the scour hole depth or the amount of sediment available in storage and the discharge magnitude. The sequence of steady discharges of different magnitudes is also important since a smaller discharge arriving after a bigger discharge is likely to find the scour hole deeper than it can scour. However, a much bigger event of high sediment scour potential can continue to scour the available sediment.

The experimental results presented in Fig. 5.7 also captured the dynamic (active) sediment storage associated with sediment supply (see section 5.4). The active sediment storage resulted in smaller scour depths with sediment supply and therefore a shift in the storage depletion curve for each steady discharge compared to when there was no sediment supply. The experimental results thus confirm that the sediment storage depletion curve is dependent on both the discharge magnitude and the sediment supply.

5.6 Non-dependence of H_{uss} on initial sediment storage

The results of the experiments with sediment supply presented in Fig. 5.6 are completed in Fig. 5.8 by including the results of sediment storage depletion after sediment supply (feed rate) had been shut off and the same steady discharge allowed to continue scouring sediment for some time in each experiment.

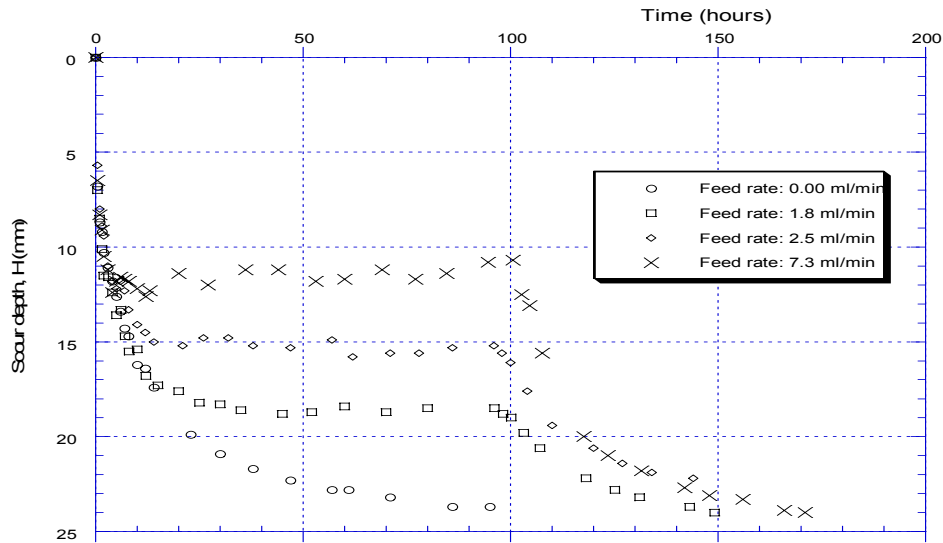


Figure 5.8: Scour depth-time relationship for a steady discharge ($Q=2.85$ litres/sec) in 100 mm width flume initially filled with sediment of $D_{50}=0.775$ mm with no sediment supply or sediment supplied at a steady rate of 1.8 ml/min or 2.5 ml/min or 7.3 ml/min for approximately 100 hours before shut off.

The sediment supplies were stopped after attaining the ultimate stable storage associated with each sediment supply for the steady discharge of 2.85 l/s. Since the stable sediment storage scour depth achieved by each sediment supply was different, the scour after sediment supply was shut off continued along different sediment storage depletion curves towards the same H_{uss} for the given steady discharge (Fig. 5.8).

The scour depth changes with time for the experiment with no sediment supply has been included to show that the tendency is to achieve approximately the same H_{uss} achieved with no supply by the experiments with supply if the scour is continued after shutting off the supply in each case. This confirms the uniqueness of H_{uss} for each steady discharge regardless of the initial sediment storage condition (H_{init} in this study). This means that if erosion is allowed to continue to infinite time after the sediment supply is shut off, scour will continue to approximately the same value of H_{uss} for each steady discharge. The experimental results also confirm the storage depletion curve concept except that it shows that it can shift its path but not its form depending on the initial sediment storage.

5.7 Sediment storage changes in three pools in series

The measured scour depth changes with time in each of the three pools in series are presented in Tables E1-E72 and Figs. 5.9-5.14. The experimental conditions are described in section 4.5 and summarized in Table 4.3.

The experimental results with both the sediment sizes of D_{50} of 0.775 mm and 1.15 mm show that the steady discharge of 11.1 litres/sec continuously deplete sediment from storage with time towards its ultimate stable state in the most upstream pool (pool 1) (Figs. 5.9 and 5.12). The sediment storage depletion rate is initially high and reduces with time as the ultimate stable state is approached. Thus a storage depletion curve and H_{uss} associated with a steady discharge can describe the sediment storage changes in the most upstream pool. Pool 1 is thus an eroding pool and acts as a sediment source to the downstream pools.

The downstream pools (pools 2 and 3) showed net fill or no change in sediment storage within the first hour of the experiment (Figs. 5.10, 5.11, 5.13 and 5.14). This was followed by net scour along a storage depletion curve towards H_{uss} of the steady discharge of 11.1 litres/sec and sediment sample of either D_{50} of 0.775 mm or 1.15 mm (Figs. 5.10, 5.11, 5.13 and 5.14).

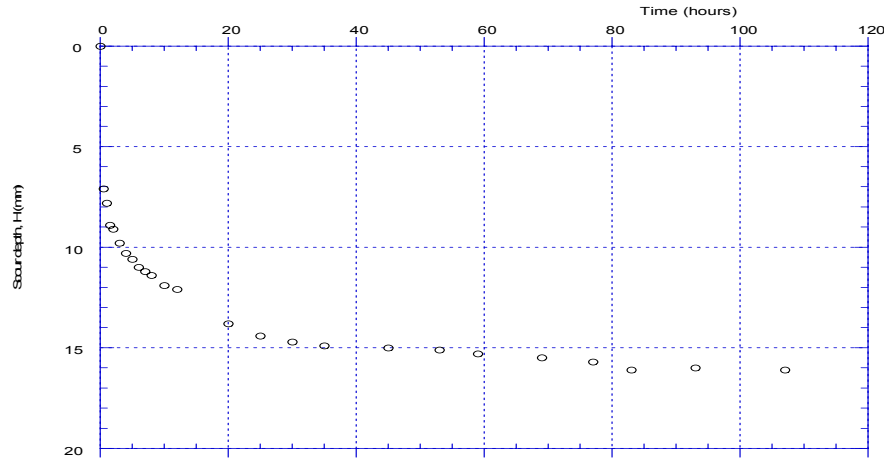


Figure 5.9: Experimentally measured scour depth-time relationship for pool 1 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/s.

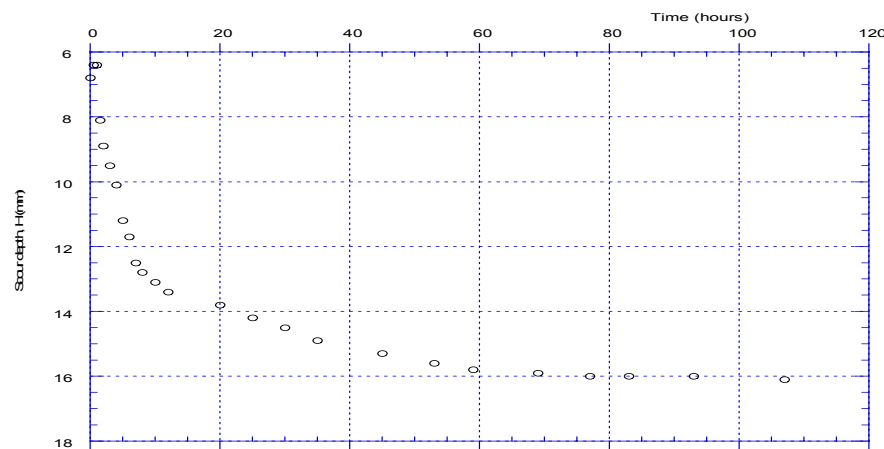


Figure 5.10: Experimentally measured scour depth-time relationship for pool 2 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/s.

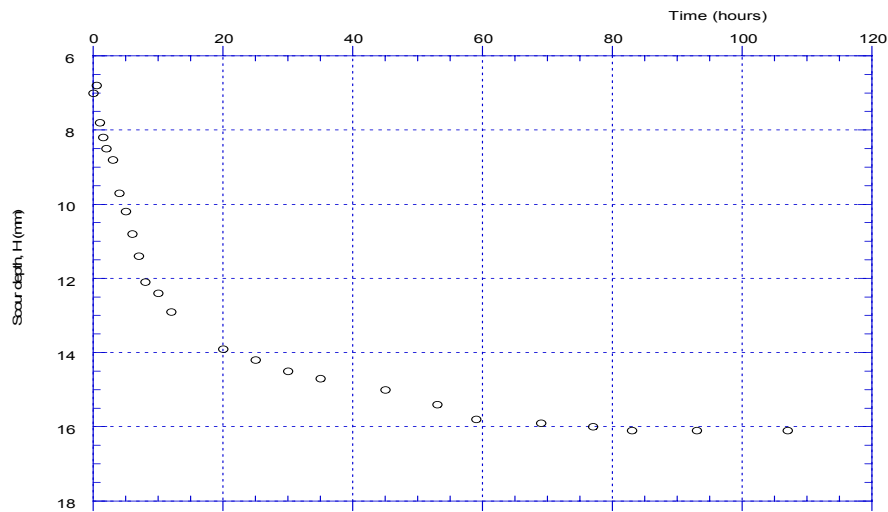


Figure 5.11: Experimentally measured scour depth-time relationship for pool 3 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/s.

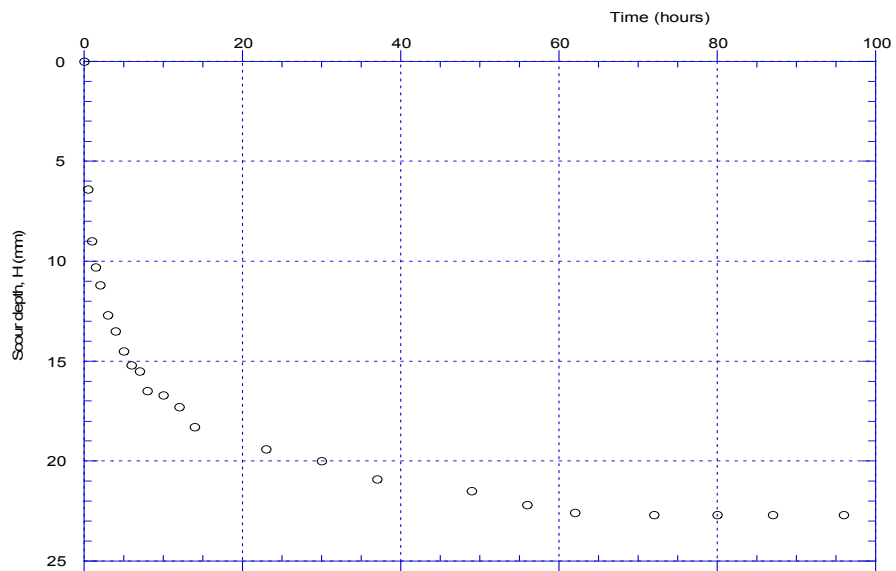


Figure 5.12: Experimentally measured scour depth-time relationship for pool 1 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/s.

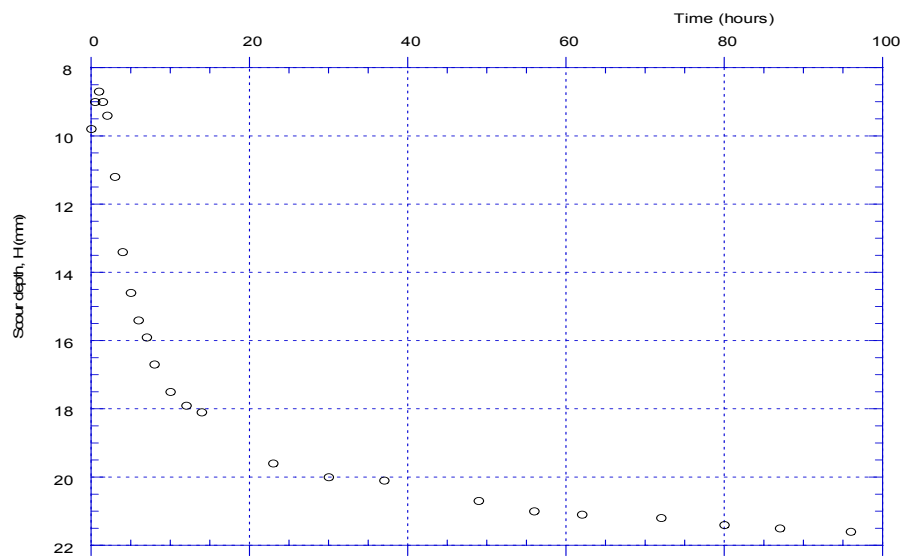


Figure 5.13: Experimentally measured scour depth-time relationship for pool 2 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/s.

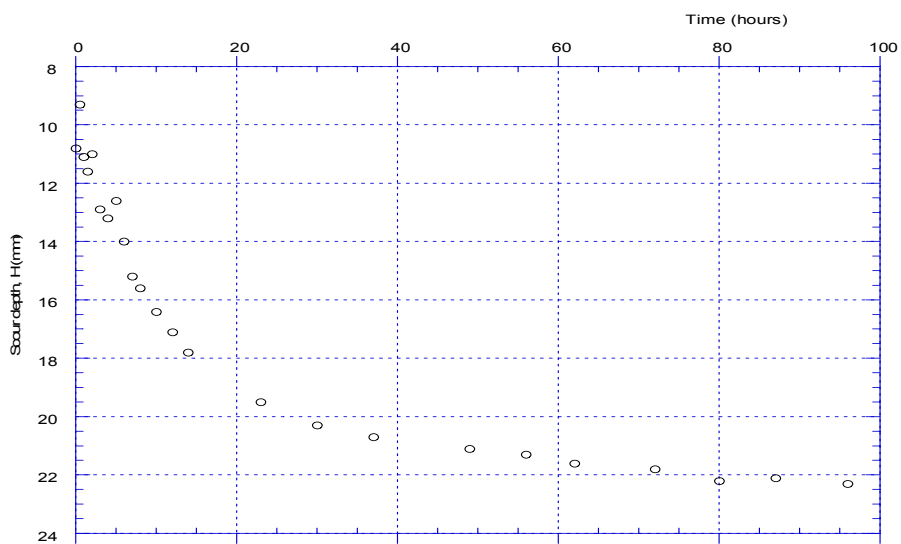


Figure 5.14: Experimentally measured scour depth-time relationship for pool 3 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/s.

The net fill or no change in sediment storage within the first one hour of each experiment has been clearly shown in Figs. 5.15-5.18 in which the sediment storage changes with time have been plotted within the first 20-25 hours. The downstream pools (pools 2 and 3 in this study) thus show both net fill and net scour. Because there was erosion in these pools even during the net fill time, the net fill can be explained in terms of high sediment supply from upstream. This means the sediment scoured from the immediate upstream pool and supplied to the immediate downstream pool during the net fill time of the downstream pool is greater than the sediment scoured and transported out of the downstream pool. Thus net sediment storage occurred in the downstream pools (pools 2 and 3). Net fill in this case means the scour depth at the end of the current time step (H_{new}) is less than the scour depth at the beginning of the current time step (H_{prev}). In other words, H_{new} is the scour depth achieved at the end of the current time step after sediment supplied and sediment in storage have been scoured. If there is no scour then all of the sediment supplied enter storage, but if there is scour then either none or part of the sediment supplied enters storage. On the other hand, H_{prev} is the scour depth at the beginning of the current time step before entry of sediment supply (H_{sup}) from upstream.

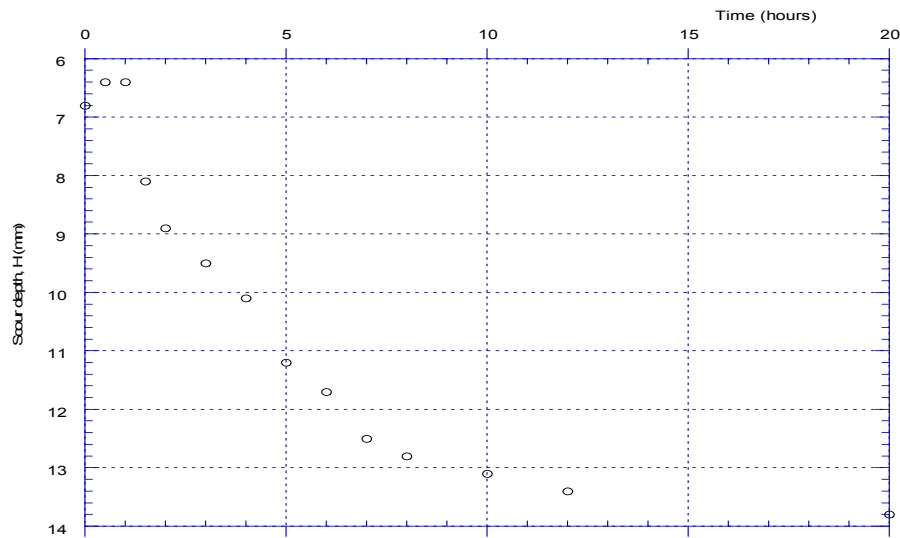


Figure 5.15: Experimentally measured scour depth-time relationship during the first 20 hours for pool 2 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/s.

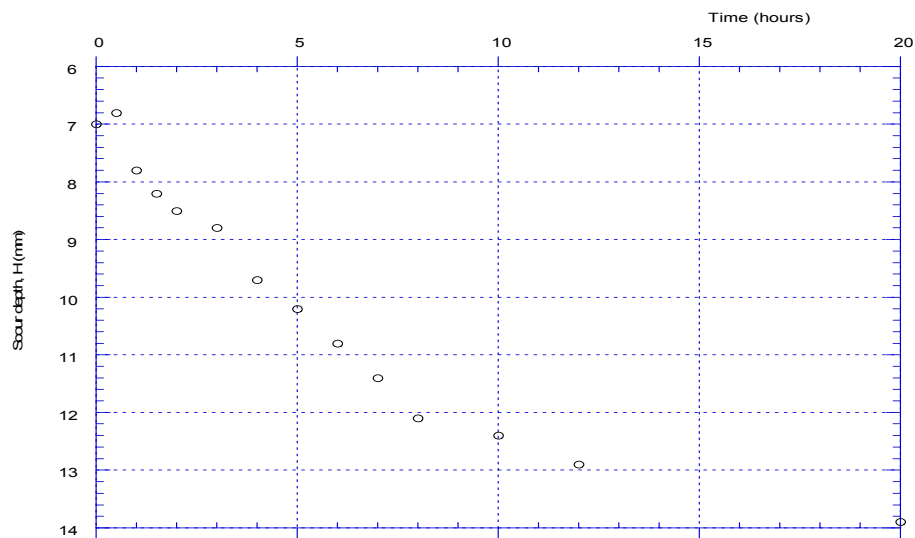


Figure 5.16: Experimentally measured scour depth-time relationship during the first 20 hours for pool 3 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/s.

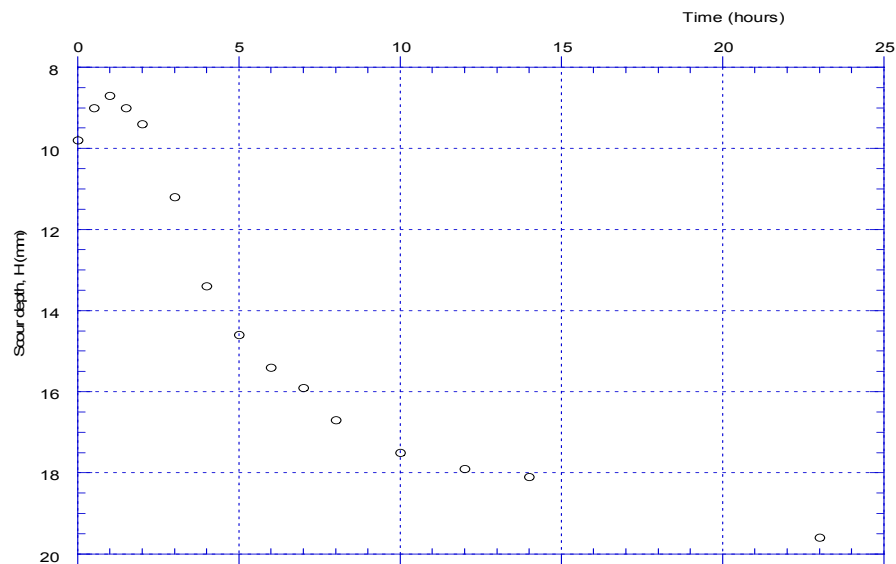


Figure 5.17: Experimentally measured scour depth-time relationship within the first 25 hours for pool 2 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/s.

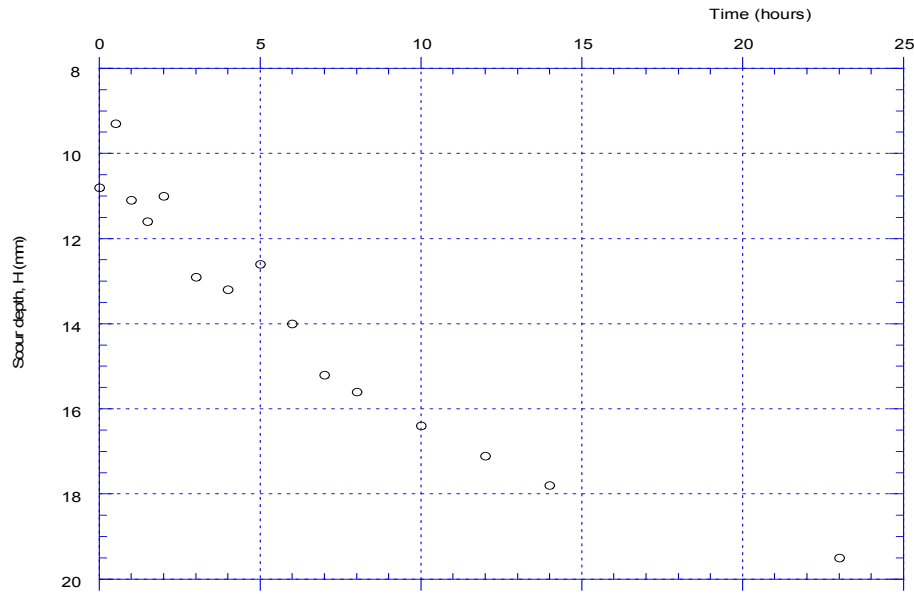


Figure 5.18: Experimentally measured scour depth-time relationship within the first 25 hours for pool 3 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/s.

It has thus been established that both the net fill and the net scour in downstream pools (pools 2 and 3 in this study) involve depletion of available sediment (sum of sediment in storage before the current time step and the sediment supply during the current time step). Thus both the net fill and the net scour can be represented by storage depletion of ($H_{\text{prev}} - H_{\text{sup}}$) along a storage depletion curve towards H_{uss} for the given steady discharge, which is 11.1 litres/sec in the current study.

The fluctuations of sediment storage changes to scour depths smaller than those along the storage depletion curve in pool 3 after the net fill time (Fig. 5.14 or Fig. 5.18) can be explained in terms of episodes of high sediment supply. This could possibly have been due to sporadic scouring of mostly fine sediments (see explanation in terms of Shields' (1936) entrainment function in section 5.3) in upstream areas with concentrated stream power. Such high sediment supply results in net fill rather than net scour. Thus for relatively fine sediments, the sediment storage change with time in downstream pools would tend to fluctuate between net fill and net scour for the greater percentage of the

scour time. However, this can only be confirmed if more experiments are performed with fine sediment samples. If this holds true, then the storage change with time may not necessarily be restricted to a particular storage depletion curve associated with a given steady discharge for such fine sediments. However, if the fluctuations of sediment storage changes with time are not very significant, then a storage depletion curve for a specific steady discharge can be estimated, for example through least squares regression.

The magnitude of sediment storage change with time has been shown to vary with sediment size in each of the pools in the series of pools regardless of the pool sequence in the series (Figs. 5.19-5.21). Coarse sediment with D_{50} of 1.15 mm has low scour depth at any given time compared with fine sediment with D_{50} of 0.775 mm in the same pool for the same steady discharge run and approximately the same initial sediment storage conditions. This can be illustrated for subsequent pools in the series through examples. Pool 2 filled with sediment of $D_{50}=0.775$ mm and corresponding pool 2 filled with sediment of $D_{50}=1.15$ mm and each subjected to the same steady discharge gave low scour depth for coarse sand ($D_{50}=1.15$ mm) compared to fine sand ($D_{50}=0.775$ mm) (Fig. 5.20). Though there were slight differences in the initial scour depths with the two different sediment sizes, the magnitude of scour depth change at corresponding times was bigger than the initial difference (Fig. 5.20). The differences were more noticeable in later time steps approaching the H_{uss} for the steady discharge and coarse sediment ($D_{50}=1.15$ mm) to fine sediment ($D_{50}=0.775$ mm). This thus showed clear differences in sediment storage changes at corresponding times due to the differences in the sediment sizes. The same observations apply to pool 3 (Fig. 5.21). This reconfirms the dependence of the magnitude of storage depletion on sediment size as shown in Fig. 5.1 and its non-dependence on pool sequence.

The H_{uss} as had been shown in Table 5.1 has been reconfirmed to depend on sediment size and does not vary with the pool sequence in the series of (seen in pools 2 and 3, Figs. 5.20-5.21). For instance the sediment storage changes with time in each of the three pools in series consistently tend towards H_{uss} of 16.1 mm for the sediment sample with D_{50} of

1.15 mm and towards H_{uss} of 22.7 mm for the sediment sample with D_{50} of 0.775 mm (Figs. 5.19-5.21).

A plot of sediment storage change with time in consecutive downstream pools (pools 2 and 3) for the same sediment size and steady discharge shows that for the same sediment size, the sediment storage change with time follows approximately the same path towards the same H_{uss} (Figs. 5.22 and 5.23). This means that the sediment storage depletion with time and H_{uss} for a specific steady discharge in consecutive downstream pools that show both net fill and net scour can be represented by the same sediment fill and depletion curves provided the sediment size and the morphology type do not change. The change in morphology type would mean for example changing from a pool-rapid channel type to anastomosing channel type in a bedrock-controlled river such as the Sabie River flowing through Kruger National Park in South Africa. This results in different rates of sediment storage change, since sediment transport and sediment storage potentials vary with the channel morphology or type.

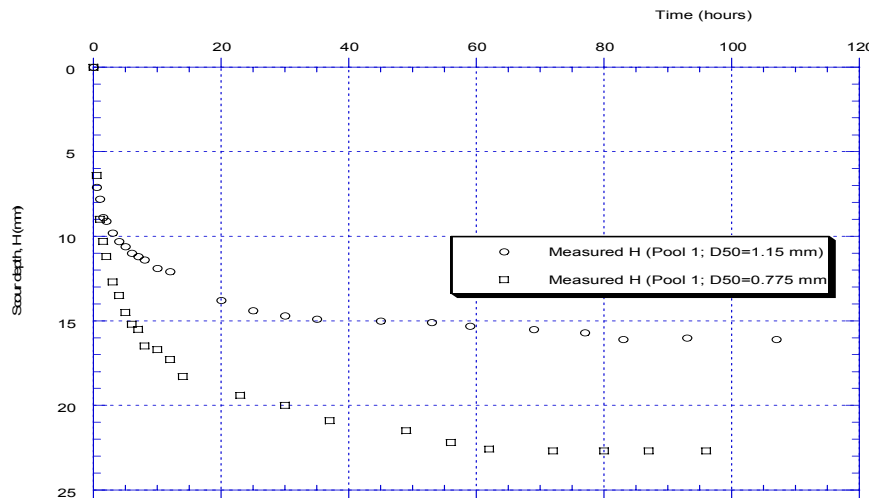


Figure 5.19: Experimentally measured scour depth-time relationship for pool 1 with sediment samples of D_{50} of 0.775 mm and 1.15 mm each at a steady discharge of 11.1 litres/s.

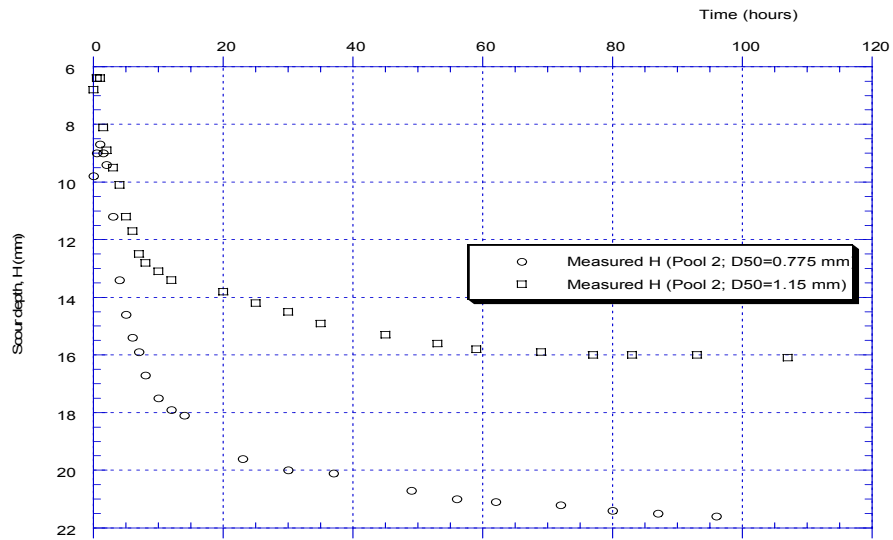


Figure 5.20: Experimentally measured scour depth-time relationship for pool 2 with sediment samples of D_{50} of 0.775 mm and 1.15 mm each at a steady discharge of 11.1 litres/sec.

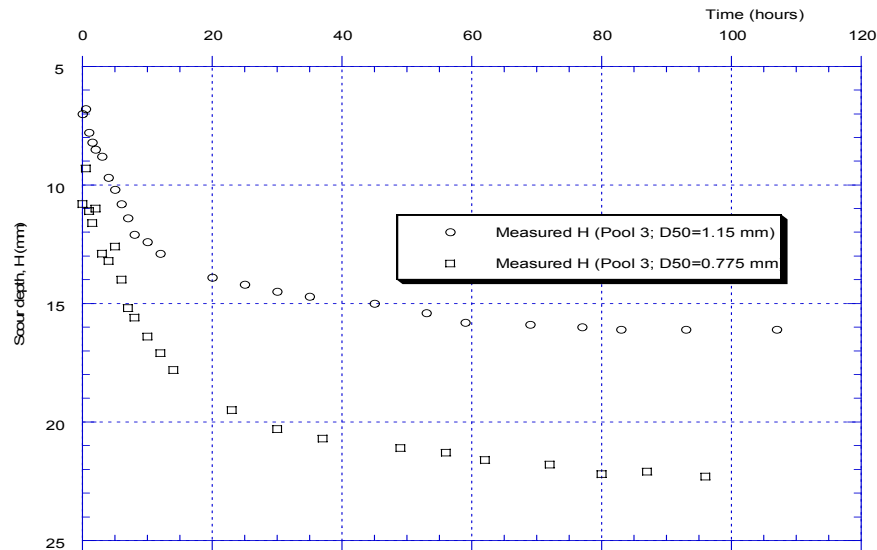


Figure 5.21: Experimentally measured scour depth-time relationship for pool 3 with sediment samples of D_{50} of 0.775 mm and 1.15 mm each at a steady discharge of 11.1 litres/sec.

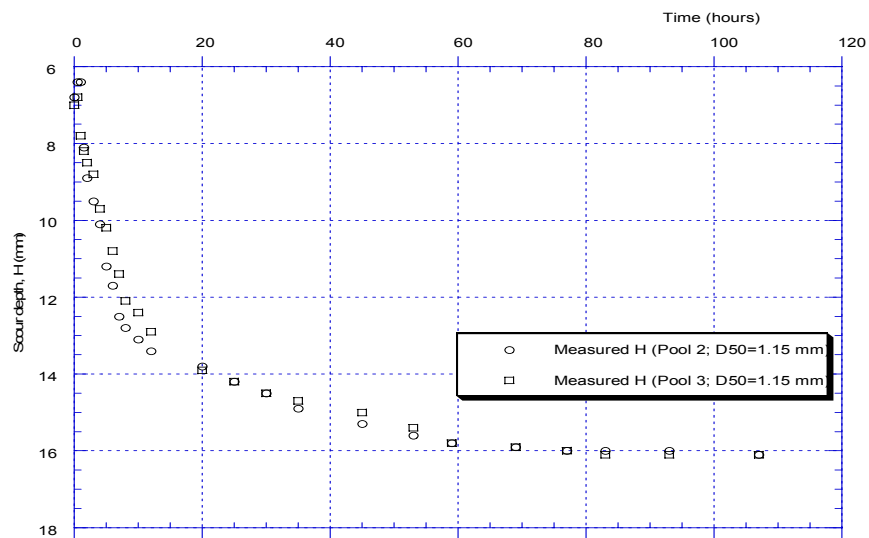


Figure 5.22: Experimentally measured scour depth-time relationship for pools 2 and 3 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/sec.

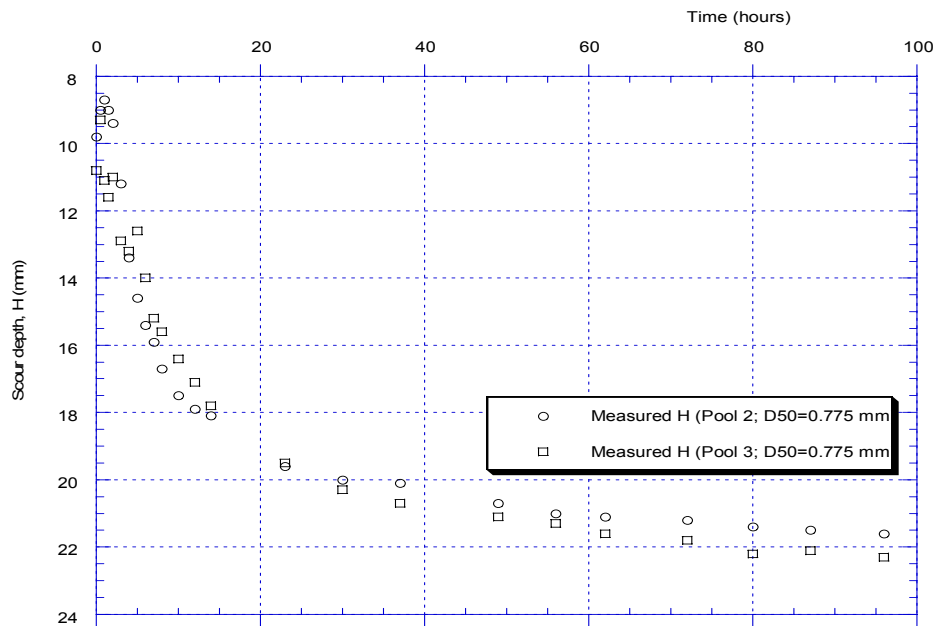


Figure 5.23: Experimentally measured scour depth-time relationship for pools 2 and 3 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/sec.

5.8 Summary

It has been shown experimentally that the sediment storage change (scour depth change with time for current application) in a pool undergoing net scour due to a steady discharge lasting for infinite time can be described in terms of the storage depletion curve and H_{uss} . The storage depletion curve and H_{uss} have been confirmed to be characteristics of any steady discharge that has the potential to scour sediment in a pool.

The sediment storage depletion curve and H_{uss} have been shown experimentally to be dependent on discharge and/or critical depth of flow (discharge magnitude and channel width), settling velocity or sediment sample size, sediment available in the channel and sediment supply. The application of the sediment storage depletion curve and H_{uss} in predicting sediment storage changes associated with any steady discharge that lasts for some time therefore needs to integrate these factors. In other words, the mathematical functions that can describe the sediment storage change with time (storage depletion) and H_{uss} need to integrate these factors as they influence the magnitude of sediment storage change. The exponential decay function proposed (Eq. 3.3) for predicting sediment storage depletion with time already has in-built into it sediment supply depth (H_{sup}), the previous time step sediment scour depth (H_{prev}) and H_{uss} . This makes it a suitable function for simulating process driven sediment storage changes in river reaches with similar or near similar geometry as the experimental channel. It can be improved on further through dimensional analysis to include the other factors affecting sediment storage change with time (scour depth change with time in the current study).

The sediment supply dependent concept of dynamic sediment storage (active sediment storage above the sediment storage depletion curve of a steady discharge proposed in section 3.11 has been confirmed experimentally. The magnitude of active sediment storage has been established to be directly dependent on sediment supply rate (Fig. 5.6). The concept of active sediment storage reaffirms the fact that both the sediment supply and discharge are important factors in budgeting sediment dynamics behind weirs or bedrock-controlled channels in the current context.

The concepts of sediment storage depletion curve and H_{uss} have been observed on the basis of experimental data to characterize sediment storage change behaviour associated with a steady discharge in a series of pools with sediment samples with D_{50} of 0.775 mm and 1.15 mm. Sediment storage changes in the downstream pools (e.g. pools 2 and 3) within the series of pools in which a steady discharge is applied have also been observed on the basis of experimental data to be characterized by both the net fill and the net scour. It is therefore important to account for both the net fill and the net scour in modelling sediment dynamics in a series of pools.

The magnitude of sediment storage change with time at any monitoring time in each of the series of pools has been found to be smaller for the coarse sediment sample ($D_{50}=1.15$ mm) than for the fine sediment sample ($D_{50}=0.775$ mm). The sediment storage change with time for the same sediment size in consecutive downstream pools (pools 2 and 3) has also been found on the basis of experimental data to nearly perfectly match each other. This shows that the sediment storage change behaviour with time applicable to any single downstream pool can be replicated in the other downstream pools of similar geometry provided the sediment sizes are the same. This has an important implication in simulation as once the sediment storage change behaviour for one downstream pool is understood, the same behaviour can be used in simulating sediment storage changes with time in subsequent downstream pools.

It has been shown on the basis of experimental results that the storage depletion curve and the unique H_{uss} for a particular discharge and sediment size is not affected by the initial sediment storage condition (initial sediment scour depth). The importance of the scour hole depth in relation to the discharge magnitude has also been confirmed experimentally. For example it has been found that a smaller discharge that has the potential to scour sediment at a given sediment storage state lacks the potential to do so after the hole has been scoured further by a bigger discharge. Thus other than the magnitude of the discharge, the state of sediment availability and the sequence of the discharge have been shown to be important factors that influence the potential to scour or not to scour sediment. These experimental results support the conceptual principle in this

study which is based on simply scouring further or filling the scour hole with sediment depending on the availability or non-availability of scour potential and sediment supply.

CHAPTER SIX

DIMENSIONLESS FORMS OF ULTIMATE STABLE SCOUR DEPTH AND STORAGE DEPLETION CURVES

6.1 Preamble

The dimensionless scour parameters of ultimate stable scour depth and storage depletion curve proposed for episodic routing of sediment in bedrock-controlled rivers are developed in this chapter. These dimensionless parameters are developed on the basis of the Buckingham π theorem and the relationships between them derived on the basis of the experimental data. The sediment properties (defined in terms of the settling velocity) and the flow conditions (defined in terms of the critical depth of flow) in addition to the gravitational acceleration which only applies for the dimensionless H_{uss} determination provide the physical variables for generating the dimensionless parameters.

6.2 Dimensionless ultimate stable scour depth

Laboratory storage depletion results show that if a constant discharge is allowed to continue for along time, sediment gets eroded towards a stable storage state associated with each constant discharge (Fig. 5.1). Since sediment storage depletion continues for a long time at a reducing rate with time towards the stable state of sediment storage, the corresponding time to the latter state of sediment storage is considered as infinite time. The state of sediment storage corresponding to infinite time has been referred to in this thesis as the ultimate stable state of sediment storage. The near flat end of each storage depletion curve (Fig. 5.1) is representative of the ultimate stable storage state.

The term ultimate stable state within the context of the definition of a steady-state equilibrium of Allen (1974) implies a steady-state equilibrium at infinite time that continues to display disequilibrium at every instant in its history. This is in recognition of the fact that erosion may continue at a non-discernible rate at infinite time. Further

support is provided by Chorley and Kennedy (1971) who defined equilibrium as a state of an open system wherein properties are invariant when considered with reference to a given time scale, but within which its instantaneous condition may oscillate due to the presence of interacting variables. Thus the ultimate stable state of sediment storage is a dynamic equilibrium state at which no changes of geomorphic significance can be discerned.

The direct dependence of H_{uss} on discharge magnitude or critical flow depth (Fig. 5.2 or Fig. 5.4) is an indicator that similar relationship holds true between these physical variables in the dependent and independent dimensionless groups containing them. The channel characteristics, flow characteristics and sediment characteristics that control the effect of discharge on the volume of sediment eroded (sections 5.2.3 and 5.2.4) provide the physical variables for forming the dimensionless groups and indicate the nature of the relationship with the ultimate stable scour depth. These characteristics in the chronological sequence provided in the preceding sentence are morphological characteristic (width in this case), critical flow condition (i.e. critical flow depth) and settling velocity of the sediment grains. Since the critical flow depth is computed from both the discharge and the width of the channel, it integrates both the flow condition and the morphological characteristic.

The most hydraulically important sediment properties are size, shape and specific gravity and these together with the flow hydraulics determine the ability of sediment to be transported. The entrainment, transportation and deposition of sediment depend upon the same factors as those affecting settling velocity (Rouse, 1950). Since settling velocity depends on the sediment size, shape and specific gravity and the viscosity of the fluid, it can be used to represent these variables in developing sediment transport and storage relationships. Sediment size (grain size) is the alternative parameter to settling velocity sometimes considered in sediment hydraulics. However, sediment size can neither be truly representative or a unique measure of sediment erodability and sediment transportability e.g. due to problems of armouring unlike settling velocity of particles which is a more significant measure in the case of non-cohesive sediment material

(Rooseboom, 1992). Thus settling velocity is an important parameter to consider in developing a parsimonious dimensionless relationship of sediment transport.

Since there is a free fall at the bedrock outcrop, the flow tends to be critical at the over fall (Henderson, 1966). This means that the bedrock outcrop acts as a control. The flow at the control is critical. This combined with the fact that the steep slope and frequent occurrence of bedrock outcrops make flow in bedrock-controlled rivers generally critical (Miller and Cluer, 1998) at or in the immediate neighbourhood of the bedrock barrier, critical flow condition was assumed. Thus the critical depth of flow was considered an important variable in defining dimensionless parameters of sediment transport.

It is important to note that in bedrock pools for which the current application has been built, flow is normally sub-critical. The use of critical depth achieved over the downstream hydraulic control for applications involving such pools as has been done in this study is based on consideration of a depth independent of sediment depletion.

The fundamental parameter of sediment movement is the ratio of a characteristic velocity of flow to the fall velocity of the sediment particles (Rouse, 1950). Different dimensionless parameters used in predicting sediment transport use different forms of flow velocity to settling velocity ratio. The velocity of flow responsible for sediment transport is in most cases (in most models of sediment transport) expressed as the shear velocity (u_*) as it is the bed shear stress that is responsible for movement of bed load. The ratio u_*/w is a measure of the balance of flow strength, represented by u_* , against the particle resistance to motion, represented by its fall velocity (w) (Henderson, 1966). Thus the ratio u_*/w is an indicator of the fluid's power to move the sediment grains.

For assumed critical flow conditions in bedrock-controlled rivers, the appropriate shear velocity would be defined as $u_* = \sqrt{(g y_c S_e)}$ where S_e is the energy slope, giving the flow velocity to settling velocity ratio of $\sqrt{(g y_c S_e)}/w$. However, the energy slope in bedrock-controlled rivers is highly variable with space and time and flow levels and distances apart would have to be measured at very close spatial and temporal intervals. This would

be very expensive if not impossible to implement despite the fact that it would give a better description of the bed velocity behaviour. In view of this, and taking into account the fact that the model to be developed can operate at a scale at which what is important is to give the directional changes of sediment storage associated with discrete discharge events, the critical velocity to settling velocity ratio will be adopted.

To describe the critical flow condition in terms of the dimensionless parameter of critical velocity of flow to settling velocity (v_c/w) for the given sediment sample of specific D_{50} , the Buckingham π theorem has been applied. Since H_{uss} has been shown to be dependent on w (Fig. 5.3) and y_c (Fig. 5.4), and considering the fact that the critical velocity of flow, $v_c = \sqrt{gy_c}$, the physical variables and/or constants to be used in the Buckingham π theorem to produce dimensionless groups are H_{uss} , y_c , w and g . Thus H_{uss} which is the dependent variable can be represented by the functional relationship given in Eq. 6.1.

$$H_{uss} = f(g, w, y_c) \quad (6.1)$$

where f is a function of and the variables are as defined earlier.

Table 6.1 shows that there are only two fundamental dimensions (L and T) in both the dependent and independent physical variables and/or constants. Thus only two repeating variables can be selected for use in the dimensional analysis by the Buckingham π theorem.

Table 6.1: The fundamental dimensions of dependent and independent physical variables

Quantity	Dimensions
H_{uss}	L
g	LT^{-2}
w	LT^{-1}
y_c	L

Since the H_{uss} is the dependent variable, it cannot be chosen as a repeating variable. Since we seek to develop a relationship between discharge (Q_w) or unit width discharge (q) and

H_{uss} , y_c which is dependent on Q_w and/or q must therefore be a component of a different dimensionless group from that of H_{uss} . The critical depth of flow can therefore not be a repeating variable. Thus, the suitable repeating variables and/or constants are g and w . The number of dimensionless groups (π groups) to be generated from the Buckingham π theorem are two ($p=n-m=4-2=2$, see appendix 6.1H).

Equations 6.2 and 6.3 can represent the Buckingham π s in terms of mathematical expressions.

$$\pi_1 = w^{a_1} g^{b_1} H_{uss} \quad (6.2)$$

$$\pi_2 = w^{a_2} g^{b_2} y_c \quad (6.3)$$

where a_1 and b_1 are exponents of w and g respectively for π_1 . Similarly, a_2 and b_2 are exponents of w and g respectively for π_2 .

Equations 6.2 and 6.3 in terms of fundamental dimensions can be rewritten in the form of Eqs. 6.4 and 6.5 respectively.

$$L^0 T^0 = (L T^{-1})^{a_1} (L T^{-2})^{b_1} L \quad (6.4)$$

$$L^0 T^0 = (L T^{-1})^{a_2} (L T^{-2})^{b_2} L \quad (6.5)$$

Equating the indices (exponents) of the corresponding fundamental dimensions on both sides of Eq. 6.4 in order to preserve dimensional homogeneity results in Eqs. 6.6 and 6.7. Similarly, equating the indices of the corresponding fundamental dimensions on both sides of Eq. 6.5 in order to preserve dimensional homogeneity results in Eqs. 6.8 and 6.9.

$$L: \quad a_1 + b_1 + 1 = 0 \quad (6.6)$$

$$T: \quad -a_1 - 2b_1 = 0 \quad (6.7)$$

$$L: \quad a_2 + b_2 + 1 = 0 \quad (6.8)$$

$$T: \quad -a_2 - 2b_2 = 0 \quad (6.9)$$

Solving Eqs. 6.6 and 6.7 simultaneously gives $a_1=-2$ and $b_1=1$. Similarly, solving Eqs. 6.8 and 6.9 simultaneously gives $a_2=-2$ and $b_2=1$. Substituting these values in Eqs. 6.2 and 6.3 gives Eqs. 6.10 and 6.11 for π_1 and π_2 respectively.

$$\pi_1 = w^{-2} g H_{uss} = \frac{g H_{uss}}{w^2} \quad (6.10)$$

$$\pi_2 = w^{-2} g y_c = \frac{g y_c}{w^2} \quad (6.11)$$

The functional relationship between the π groups is thus as given in Eq. 6.12.

$$\frac{g H_{uss}}{w^2} = f\left(\frac{g y_c}{w^2}\right) \quad (6.12)$$

and all the variables and constants are as defined earlier.

The dimensionless ultimate stable scour depth $(\sqrt{g H_{uss}})/w$ was found to collapse on a straight line when fitted against the ratio of critical velocity of flow (representing flow condition) and settling velocity (representing sediment characteristics or transportability of sediment materials) i.e. $(\sqrt{g y_c})/w$ from experimental data (Fig. 6.1; Eq. 6.13).

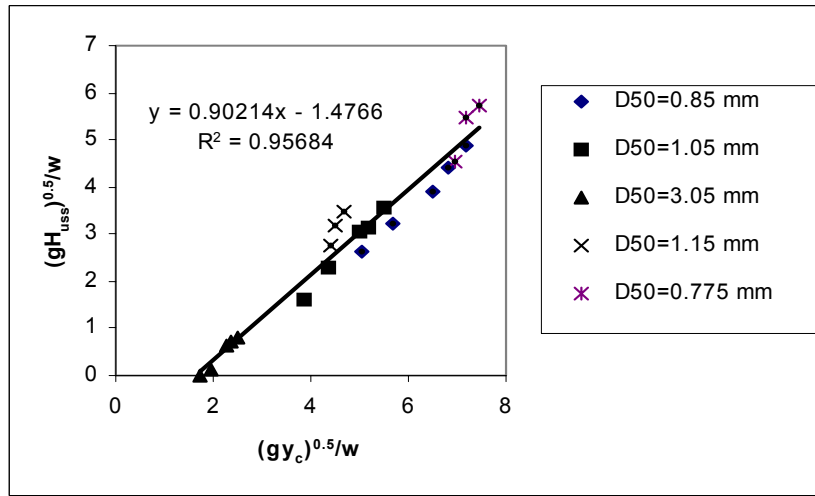


Figure 6.1: Dimensionless relationship of H_{uss} and critical depth of flow

$$\frac{\sqrt{g H_{uss}}}{w} = 0.90214 \frac{\sqrt{g y_c}}{w} - 1.4766 \quad (6.13)$$

Thus the appropriate forms of the dimensionless groups (π groups) of H_{uss} and y_c derived in Eqs. 6.10 and 6.11 respectively are their square roots. Thus the experimental data

shows linear dependence of the theoretically derived dependent dimensionless group of $(\sqrt[3]{gH_{uss}})/w$ on the theoretically derived independent dimensionless group of $(\sqrt[3]{gy_c})/w$. Thus the experimental scour depth changes with discharge for sediment of different representative sediment sizes were useful in determining the appropriate form of the relationship between the dimensionless H_{uss} and y_c or Q_w for the pool geometry.

The dimensionless group $(\sqrt[3]{gy_c})/w$ is the ratio of v_c/w and can be alternatively derived from first principles for a rectangular channel as shown in Eq. 6.14.

$$\frac{Q_w}{wby_c} = \frac{q}{wy_c} = \frac{y_c v_c}{wy_c} = \frac{v_c}{w} = \frac{\sqrt{gy_c}}{w} \quad (6.14)$$

The use of dimensionless parameters allows integration of the significant variables of sediment transport in describing the relationship between discharge and either the volume or depth of sediment eroded in each geomorphic unit of consideration. Dimensionless parameters of sediment transport derived at a different geomorphic scale can be applied at another scale. This requires similarity in dynamic processes and physical parameters influencing geomorphic change. For example dimensionless parameters developed on the basis of laboratory results can be applied at the field scale. However, the flow condition, sediment characteristics and channel characteristics must be similar or follow established geometric and dynamic scaling principles.

The results (Fig. 6.1) show that the dimensionless relationships are only to a limited extent dependent on sediment samples of different D_{50} but in general show a linear relationship. This simply means that the use of sediment samples of different D_{50} in experimental investigations do not cause major shifts in the form of the dimensionless relationships. However, sediment samples of specific D_{50} still do influence the magnitude of scour depth directly and indirectly through settling velocity. This is because the amount of sediment scoured by each discrete discharge is dependent on sediment of specific D_{50} (Fig. 5.1). The relationship between sediment of specific D_{50} and the scour depth would however be much more complex as the representative sediment size (D_{50}) is only an approximation as there are particles of different sizes moving at different rates for each constant discharge.

The ability of dimensional analysis in transforming scale dependent relationship between H_{uss} and y_c or Q_w to a more general relationship for all the sediment sizes shows the ability of the developed method to apply at any river scale with granular sediment material on transport. This demonstrates the potential of non-dimensional relationships in providing process-based model parameters.

6.3 Dimensionless storage depletion curves

Since settling velocity has been found to adequately represent the sediment size (section 6.2) the dependence of sediment storage depletion on sediment size can be treated as equivalent to dependence on settling velocity. Thus settling velocity is an important variable influencing sediment storage depletion.

In summary, based on experimental results on storage depletion associated with discrete discharges and sediment samples of different D_{50} and their interpretation (section 5.3), settling velocity (representing sediment characteristics), discharge and channel width (morphological attribute) influence sediment storage depletion. To describe the flow condition and morphological effect, the critical flow depth as assumed in section 6.2 for bedrock-controlled rivers will be adopted to integrate discharge and channel width in a unit width discharge. The unit width discharge integrates channel morphology in its influence on sediment storage depletion.

Equation (3.3) (sediment storage exponential decay equation) hypothesized to describe erosion associated with each discrete discharge event when there is sediment supply was subjected to the experimental conditions to generate the storage depletion equation for the experimental pool. The relevant experimental conditions included the channel initially filled with sediment ($H_{prev}=0$) and no sediment supply ($H_{sup}=0$). This results in a sediment storage depletion equation for each discrete discharge event and each sediment size (Eq. 6.15).

$$H_{new} = H_{uss} (1 - \exp(-kt^\phi)) \quad (6.15)$$

The parameters and/or variables in this equation are as described in section (3.9). Equation (6.15) can be expressed in dimensionless form as follows (Eq. 6.16).

$$1 - \frac{H_{new}}{H_{uss}} = \exp(-kt^\phi) \quad (6.16)$$

Since the sediment storage depletion up to infinite time varies with sediment size, discharge and channel width (Fig. 5.1), the physical variables of sediment settling velocity and critical flow depth influence scour with time up to ultimate stable state. Dimensional analysis can be carried out with sediment settling velocity, critical depth of flow and the elapsed time (t) as physical variables to produce a dimensionless group that ensures that the exponent of the exponential function in Eq. 6.16 is dimensionless. This apart from ensuring dimensional homogeneity ensures that the k, which is part of the exponent of the exponential function of the storage depletion curve (Eq. 6.16), is a dimensionless constant with no dimensions or physical measuring units.

The fundamental dimensions of w and y_c are provided in Table 6.1 and the fundamental dimension of t is T. The total number of physical variables is three ($n^*=3$). The scour depths H and H_{uss} are not considered in the dimensional analysis, as they are already part of a dimensionless constant ($1-H/H_{uss}$) in the left-hand side of Eq. 6.16. Two repeating variables can be selected for use in the dimensional analysis by the Buckingham π theorem since all the physical variables are made up of only 2 fundamental dimensions (L and T). The number of dimensionless groups is 1 (i.e. $p=n^*-m=3-2=1$, see appendix 6.1H). The Buckingham π can be represented in terms of mathematical expression as shown in Eq. 6.17.

$$\pi = w^{a_0} y_c^{b_0} t \quad (6.17)$$

where a_0 and b_0 are exponents of w and y_c respectively.

Equation 6.17 can be expressed in terms of fundamental dimensions as shown in Eq. 6.18.

$$L^0 T^0 = (L T^{-1})^{a_0} L^{b_0} T \quad (6.18)$$

Equating the indices of the corresponding fundamental dimensions on both sides of Eq. 6.18 results in Eqs. 6.19 and 6.20.

$$L: \quad a_0 + b_0 = 0 \quad (6.19)$$

$$T: \quad -a_0 + 1 = 0 \quad (6.20)$$

Solving Eqs. 6.19 and 6.20 simultaneously gives $a_0=1$ and $b_0=-1$. Substituting these values in Eq. 6.17 for π gives Eq. 6.21.

$$\pi = wy_c^{-1}t = \frac{wt}{y_c} \quad (6.21)$$

Thus Eq. 6.16 can be rewritten as (Eq. 6.22):

$$1 - \frac{H_{new}}{H_{uss}} = \exp\left(-k\left(\frac{wt}{y_c}\right)^\phi\right) \quad (6.22)$$

The parameter ϕ was estimated through optimization. This involved trying different exponents of time until the one that fits experimental data optimally on Eq. (6.22) is achieved. The optimal least squares fit gives the values of k and ϕ for the optimized integrated dimensionless storage depletion curve (Fig. 6.2).

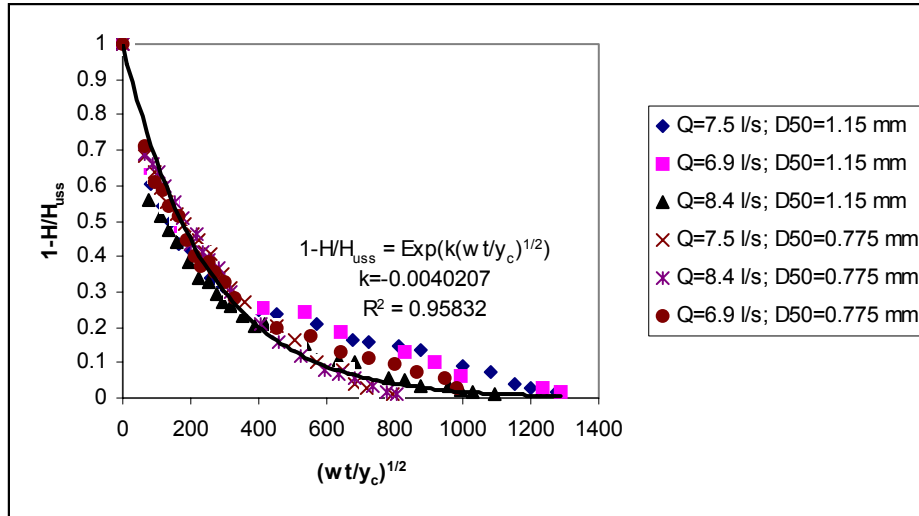


Figure 6.2: Dimensionless sediment storage depletion curve

The optimized integrated dimensionless storage depletion curve can be expressed as given in Eq. 6.23.

$$1 - \frac{H_{new}}{H_{uss}} = \exp(-0.0040207 \sqrt{\frac{wt}{y_c}}) \quad (6.23)$$

Comparison of Eq. (6.22) and Eq. (6.23) gives ϕ and exponential decay factor (k) as 0.5 and 0.0040207 respectively. Thus for any discrete discharge event the scour depth along the sediment storage depletion curve at the end of any time (t) is described in terms of the exponential decay function (Eq. 6.24).

$$H_{new} = H_{uss} (1 - \exp(-0.0040207 \sqrt{\frac{wt}{y_c}})) \quad (6.24)$$

The optimization of the dimensionless form of the storage depletion curve (Eq. 6.22) using experimentally derived scour data to determine the storage depletion parameters of exponential decay factor (k) and the exponent of elapsed time (ϕ) (Eq. 6.23; Fig. 6.2) constitutes the calibration of the model. Similarly, H_{uss} may be considered as having been calibrated from the dimensionless fit on the experimentally derived ultimate stable scour data (Eq. 6.13; Fig. 6.1).

The results used to produce sediment storage depletion curve (Fig. 6.2) involved a number of experimental runs. Each experimental run involved the use of a steady discharge and sediment size with D_{50} of 0.775 mm or 1.15 mm with (see section 4.5 for details). The generation of integrated storage depletion curve for both the sediment samples each of specific D_{50} is an indication that the method may be applicable for a wide range of sediment sizes that move as bed load. Thus the method has potential for wide application in pools constituted of different sediment sizes. This means we can apply the storage depletion curve derived using this method in different natural river environments made up of pools with sediment that can move as bed load.

In later experimental monitoring time steps, most of the fine and light sediments would have been scoured leaving behind coarse and heavy sediment particles that are difficult to move particularly with relatively low discharges (Shields, 1936). The resulting small scour depth from coarse and heavy sediments thus results in a high value of the ordinate

$(1-H/H_{uss})$. This thus explains the reason why at the abscissa $\sqrt{(wt/y_c)} > 300$, there is significant divergence in the ordinate $(1-H/H_{uss})$ from the integrated optimized best-fit curve particularly for coarse sediment ($D_{50}=1.15$ mm) and relatively low discharges of 6.9 l/s and 7.5 l/s (Fig. 6.2). Due to the same reasons given by Shields' (1936), fine and light sediments ($D_{50}=0.775$ mm in this case) might have over scoured thus causing the integrated optimized least squares fit to tend towards the fit for the fine and light sediments. This causes high scour depth (H) and thus results in underestimation of the sediment storage depletion ordinate $(1-H/H_{uss})$. This means it takes long to scour as much coarse and heavy sediment as fine and light sediments. The abscissa values $(\sqrt{(wt/y_c)})$ at any time t are widely spread because the abscissa is affected either by w if the sediment sizes are different and the discharge is the same or by y_c if the discharges are different but the sediment sizes are the same (Fig. 6.2). This holds provided the width is constant in all the cases. However, for cases where both the sediment sizes and the discharges are different, the value of the abscissa is affected by both the settling velocity and the critical depth of flow (Fig. 6.2).

The experimental results on optimized fit confirm sediment storage depletion relationship as a recession curve that takes the form of exponential decay (Eq. 6.23 or Eq. 6.24; Fig. 6.2) as discussed in section 3.9. The sediment storage depletion curve thus approaches the H_{uss} asymptotically (Fig. 6.2). This confirms the hypothesized theory of sediment storage depletion curves associated with each steady discharge as being exponential and asymptotic to H_{uss} (Eq. 3.3). The experimentally calibrated sediment storage depletion equation (Eq. 6.24) is proposed for use in routing sediment in pools found in bedrock-controlled rivers in its current form provided there is no sediment supply and the channel is initially completely filled with sediment. However, for cases where there is sediment supply and where the channel is not initially completely filled with sediment, the dimensionless form of Eq. 3.3 with k and ϕ determined from least squares optimization is proposed for computing sediment storage depletion with time. The appropriate forms of both the equations (the dimensionless form of Eq. 3.3 and Eq. 6.23) will, however, be modified to account for sediment translation (characteristic of sediment transport in

bedrock-controlled rivers) and other types of sediment storage morphologies in bedrock-controlled rivers (see section 3.10 and sub-section 7.4.3).

6.4 Summary

The Buckingham π theorem has been used to find the dimensionless parameters of both the H_{uss} and the storage depletion curve. The critical flow depth, which integrates the flow condition (discharge) and the morphological characteristic (width), and the settling velocity, which represents the sediment transport characteristics have been found suitable as independent physical variables for generating the dimensionless groups. The gravitational acceleration (g) was found suitable as an additional constant for generating the dimensionless H_{uss} .

The experimentally measured scour depth change with time and at ultimate stable state have been used to calibrate the non-dimensional forms of the storage depletion curve and the H_{uss} versus discharge for the given pool geometry. These process-based relationships though empirical in nature (Eqs. 6.23 and 6.13 respectively) are representative of the process-form interactions as they are determined on the basis of fundamental physical interacting variables in bedrock-controlled rivers. The ability of the developed equations to characterize the bedrock-controlled river systems of the pool type in terms of the relationship between the dimensionless forms of the physical variables influencing the system behaviour can permit the sediment storage dynamics to be described at the scale of consideration. In this thesis because the sediment scour parameters determined at a more controlled system in the laboratory will be applied in modelling a more erratic natural bedrock-controlled river system, the modelling scale of resolution is considered coarse.

The ultimate stable storage (the H_{uss} in this case (Eq. 6.13)) for each steady discharge for the given channel geometry has been proposed for providing the ultimate sediment budget potential in bedrock-controlled rivers. It can therefore be used in sediment budgeting by simply comparing it with the available sediment storage and/or supply to

determine the availability of either scour potential or sediment storage potential. On the other hand the sediment storage depletion curve has been confirmed to follow the principles of recession (exponential decay) (section 6.3) and with the ultimate stable scour depth in-built in it (Eq. 6.24), it has been proposed for quantifying sediment storage depletion with time. The need to use the generalized form of the storage depletion equation that accounts for sediment translation, sediment supply/availability and other sediment storage morphologies characteristic of bedrock-controlled rivers has been identified.

The ability of dimensional analysis to collapse scattered data points into a mathematically definable line or curve has been demonstrated for both the H_{uss} and the storage depletion curve. This has been achieved despite the multifarious nature of sediment transport variables. Thus dimensional analysis is a powerful tool for modelling sediment storage changes in natural river environments with complex sediment-flow-morphology interactions such as bedrock-controlled rivers.

In summary, the experimentally calibrated dimensionless H_{uss} and storage depletion curve have been proposed as fundamental parameters for routing sediment in bedrock-controlled rivers. However, the current dimensionless forms of H_{uss} (Eq. 6.13) and storage depletion curve (Eq. 6.23) apply to bedrock pools at the morphological unit scale or pool-rapid at the channel type scales (one of the morphology types and channel types respectively found in bedrock-controlled Sabie River (Van Niekerk and Heritage, 1993)). Thus to produce a complete model that covers all the different morphology classes or channel types in a complex bedrock-controlled river like the Sabie River, similar or near similar relationships have to be determined for other morphology types or channel types.

CHAPTER SEVEN

MODEL DEVELOPMENT, MODEL RESULTS AND EXPERIMENTAL CONFIRMATION

7.1 Preamble

The inverted episodic sediment budget model is developed and verified in this chapter. The H_{uss} and the storage depletion curve associated with discrete discharges in dimensionless forms (sections 6.2 and 6.3 respectively) together with simple mass balance equation are applied in the development of the inverted episodic sediment budget model. The model is aimed at routing sediment in a series of morphology classes or channel types characteristic of bedrock-controlled rivers, such as the Sabie River in South Africa. Sediment storage changes for discrete discharges lasting for some time in a single or a series of simple laboratory simulated pools have been used in the verification of the model. This is aimed at simply demonstrating the potential of the discrete discharge events modelling concepts (H_{uss} and storage depletion curve) in routing sediment in bedrock pools. The concept can henceforth be extended for general use in other morphology types in bedrock-controlled rivers.

The sediment routing procedure based on principles proposed for routing sediment in bedrock-controlled rivers presented in section 3.9 is explained in this chapter. The sediment routing conceptual principle is based on the relative position of the scour depth after receiving the sediment supply ($H_{prev}-H_{sup}$) during each routing period in relation to the H_{uss} of the steady discharge event.

The appropriate form of the sediment storage depletion curve suitable for routing sediment in bedrock pools in cases with sediment supply and with no sediment supply is presented in this chapter. The treatment of the sediment supply in the model in terms of the trapezoidal layers and the method for computing the lengths of the sediment layers are also presented.

A set of model results and their corresponding experimental verification results are presented to establish the effect of sediment supply on the H_{uss} and the storage depletion curve for each steady discharge and confirm the uniqueness of H_{uss} for each steady discharge and its non-dependence on initial sediment storage.

Another set of model results and their corresponding experimental verification results are presented to confirm the fact that in sediment routing with a series of steady discharges using the inverted episodic sediment budget model, each steady discharge routes sediment along its storage depletion curve towards its H_{uss} . The latter model results and their corresponding experimental results were mainly aimed at validating the conceptual sediment routing principle that scour cannot occur if the scour hole is already deeper than the H_{uss} . In this case sediment supply can only be added to the scour hole. Thus both the model results and their corresponding experimental results seek to validate both the sediment storage depletion and the sediment storage component of the inverted episodic sediment budget model. It is important to note that the latter model results and their corresponding experimental results could also be used to confirm that each steady discharge scours sediment along its storage depletion curve towards its unique H_{uss} regardless of the initial sediment storage condition provided there is scour potential. This validates the storage depletion concept in the inverted episodic sediment budget model (section 3.9).

The inverted episodic sediment budget model is applied to route sediment dynamics in three pools in series. The model involves application of a constant discharge that lasts for a long time and routes sediment in each pool until ultimate stable state of sediment storage is attained. This is aimed at demonstrating the applicability of the inverted episodic sediment budget model in a series of pools. The model results for the three pools in series are verified with the corresponding experimental results.

Chapter three broadly proposes the conceptual sediment routing approach without providing the implementation details or the detailed routing procedure. This is unlike the current chapter, which expounds the details of the sediment routing procedure. The

modelling concept and approach is fully developed, verified and its potential applicability demonstrated in this chapter.

7.2 Representation of the spatial units in the model

Each channel or pool for the laboratory application will be represented in the model by a single cell of characteristic length and width. Each cell length will be equivalent to the distance from the start of the tilting section of the flume to the simulated bedrock outcrop (obstruction) for the upstream cell. However, when a series of cells are considered, the distance from the upstream simulated bedrock outcrop to the next downstream simulated bedrock outcrop will constitute the cell length of each downstream cell. The width of each cell will be that of the experimental channel.

7.3 Representation of infinite duration steady discharge in the model

The experimental scour monitoring times for steady discharges lasting for some time have been adopted as sediment routing times in the model. The experimental scour monitoring times are the times from the beginning of the experiment when scour depth changes were measured. For example for a steady discharge (Q_w), the scour time $t(i)$ is the scour monitoring time at the i^{th} time since the beginning of the experiment or model (Fig. 7.1). This made it easier to produce the corresponding results from the experiment and the model in the same graphical display for easier comparison.

For improved scour results it is recommended that the modelling and measuring times be made very small. However, this has practical limitations for the long duration experiments. The high frequency of monitoring at short time intervals would require a number of monitoring staff working in rotational schedules. This was, however, not financially feasible in this project. Automating the measuring equipment if the financial resources were sufficient to permit this would also have reduced the high staff monitoring demand. As discussed in section (5.3) the frequent disturbance of the sediment surface lowers the accuracy of the cumulative scour depth especially for relatively fine

sediments, for example the relatively fine experimental sediment sample with D_{50} of 0.775 mm.

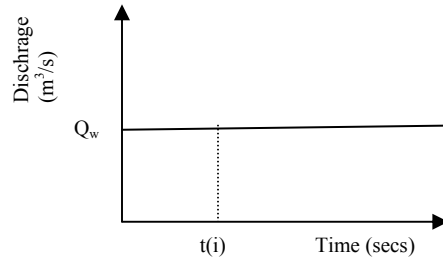


Figure 7.1: Steady discharge hydrograph

7.4 Sediment routing details

The sediment routing approach or procedure based on the concepts of H_{uss} , storage depletion curve and sediment available and/or sediment supply as coded in Visual Basic is explained in this section.

7.4.1 Sediment routing logic or procedure

The sediment routing logic or procedure using inverted episodic sediment budget model for a steady discharge lasting for some time is presented in Fig. F1. The use of a steady discharge is based on the assumption of a flood peaking to a certain discharge magnitude in the river and maintaining that discharge magnitude for some time before recession begins or another flood of a different peak discharge magnitude occurs. This concept can be extended to simulate sediment storage changes linked to a series of steady discharges, each of which increases or decreases after some time (Figs. 7.2 and 7.3).

The sediment routing procedures all begin by testing if the H_{uss} for the steady discharge is greater or less than the sum of the scour depth at the previous time step and the supply depth at the end of the current time step (i.e. $(H_{prev} - H_{sup})$) if there is sediment supply. The sediment routing is assumed to be instantaneous at the end of each time step. If there is

no sediment supply then the sediment routing procedure tests if the sediment storage before the current time step (H_{prev}) is greater than or less than the H_{uss} for the steady discharge. Thus based on the conceptual principles presented in section 3.9, the sediment routing procedures for each steady discharge are structured as follows. If there is sediment supply and $(H_{\text{prev}} - H_{\text{sup}}) > H_{\text{uss}}$ then there is no potential to scour the sediment and the new scour depth is given by $H_{\text{prev}} - H_{\text{sup}}$ while if there is sediment supply and $(H_{\text{prev}} - H_{\text{sup}}) < H_{\text{uss}}$, then the scour potential exists. If there is no sediment supply and $H_{\text{prev}} > H_{\text{uss}}$ then there is no potential to scour the sediment and the previous sediment storage (H_{prev}) is upheld while if there is no sediment supply and $H_{\text{prev}} < H_{\text{uss}}$, then the scour potential exists.

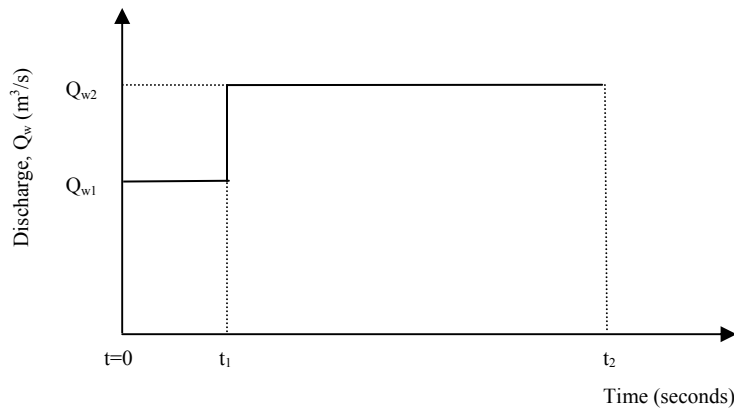


Figure 7.2: Increase in steady discharge (Q_{w1}) of duration t_1 to steady discharge (Q_{w2}) of duration $(t_2 - t_1)$.

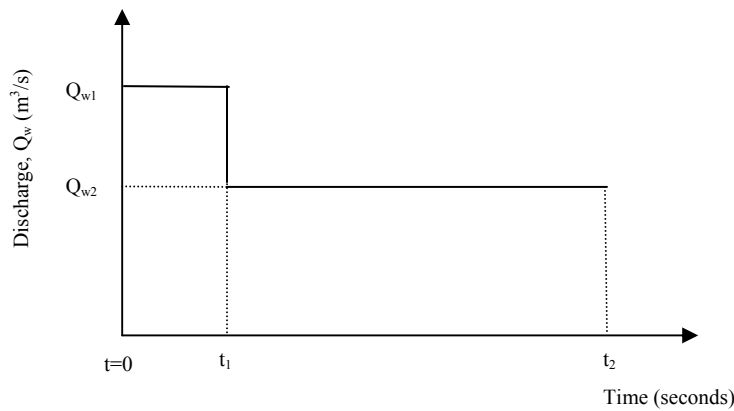


Figure 7.3: Decrease in steady discharge (Q_{w1}) of duration t_1 to steady discharge (Q_{w2}) of duration $t_2 - t_1$.

The sediment budget dynamics involves filling the scour hole with sediment or scouring sediment from it. Thus the modelling principle involves adjusting the volume (the depth in this case) of the scour hole. The depth of the scour hole either increases or decreases depending on the availability of the scour potential and the storage potential as discussed in section (3.9). The situation is much more complex with sediment supply since even if the scour potential exists the volume of sediment supply and the length of the routing time step according to the same routing principles presented in section 3.9 determines whether net scour or net fill occurs. Thus the modelling procedure must also account for net fill and net scour along the storage depletion curve for each steady discharge.

The sediment particle size and the sediment particle density according to Shields' (1936) entrainment function, control the volume of sediment supplied from upstream cells or from catchment source erosion. The scour or sediment storage depletion is described by the appropriate form of the storage depletion curve as discussed in section 6.3, coupled with the appropriate form of the translation module when necessary (sub-section 7.4.3). If the channel undergoes net scour, the translation module is included to account for the fact that the transfer of all the coarse and dense sediment particles of low sediment velocity from upstream may take longer than the model time step. If net fill occurs, a translation module is included to account for the fact that though finer and lighter sediment particles are of high sediment velocity their transfer may take longer than the model time step particularly because of the armouring effect. However, they are likely to be transferred faster than the coarser and denser sediment particles of low sediment velocity. The details of the translation module are found in sub-section 7.4.3.

The modelling procedure for each steady discharge is developed for a series of cells with the discharge each time scouring or depositing sediment towards its H_{uss} value, which gives scour or storage potential. Further details of the model include checking whether the supplied sediment fills the channel beyond its full capacity ($(H_{prev}-H_{sup})<0$, i.e. negative), at its full capacity ($H_{prev}-H_{sup}=H_{fullCap}=0$) or does not fill the channel to its full capacity ($(H_{prev}-H_{sup})>0$).

Sediment scoured from the immediate upstream cell transported to the immediate downstream cell at any modelling time step is computed from Eq. 7.1 if there is sediment supply and from Eq. 7.2 if there is no sediment supply. The sediment scour and the sediment storage are assumed to occur in trapezoidal layers.

$$Q_{sout} = [H_{new} - (H_{prev} - H_{sup})]A_{scr} \quad (7.1)$$

$$Q_{sout} = [H_{new} - H_{prev}]A_{scr} \quad (7.2)$$

where, A_{scr} is the area of scoured layer of sediment and the rest of the variables are as defined earlier (section 3.9). However, if the sediment supply fills the channel beyond its full capacity then the sediment scoured is given by the sum of the excess sediment above the full channel capacity and the sediment scoured along the storage depletion curve from the top of the filled channel ($H=0$) (Eq. 7.3). If the sediment supply fills the channel beyond its full capacity ($(H_{prev}-H_{sup})<0$) and there is no scour potential then the excess volume of sediment above the full channel storage capacity is transferred to the next cell (Eq. 7.4), leaving the channel filled with sediment to its full storage capacity. This applies to a situation where there is no discharge-related scour potential but non-water sources such as wind, earth movements, etc., transport sediments into the channel. The assumption in this case is that other factors such as the steep gradient that commonly characterizes bedrock-controlled rivers makes it possible to move excess sediment above the full sediment storage capacity of the channel to the next downstream cell.

$$Q_{sout} = -(H_{prev} - H_{sup})A_{top} + H_{new}A_{scr} \quad (7.3)$$

$$Q_{sout} = -(H_{prev} - H_{sup})A_{top} \quad (7.4)$$

where, A_{top} is the cross-sectional area of the top of the channel filled with sediment and the rest of the variables are as defined earlier (section 3.9). The sum of H_{prev} and H_{sup} (i.e. $H_{prev}-H_{sup}$) is negative and accounts for the excess sediment above the full capacity of the channel. It is therefore negated in Eq. 7.3 and Eq. 7.4 to give the excess sediment above the full sediment storage capacity of the channel.

The time varying scour rates of steady discharge events that last for some time and have the potential to scour sediment are illustrated by both the net scour and the net fill observed in the downstream pools (section 5.7) and in-built in Fig. F1 and Code G1 by

making use of different translation modules accounting for the differences in the sediment particle velocities that result in either net scour or net fill.

In summary the sediment routing procedures set out in Fig. F1 and coded in Visual Basic (Code G1) are essentially sediment scour modules and sediment storage modules.

7.4.2 Sediment routing time

Trial testing on Eqs. 7.5 and 7.6 confirm that these two different forms of the storage depletion equation (Eq. 3.3) with the parameter ϕ having been determined from optimization as 0.5 (section 6.3) results in the same scour depth (H_{new}).

$$H_{\text{new}} = H_{\text{uss}} + (H_{\text{prev}} - H_{\text{uss}}) \exp\left(-k \sqrt{\frac{w}{y_c}} \Delta\sqrt{t}\right) \quad (7.5)$$

$$H_{\text{new}} = H_{\text{uss}} + (H_{\text{init}} - H_{\text{uss}}) \exp\left(-k \sqrt{\frac{wt}{y_c}}\right) \quad (7.6)$$

where, H_{init} is the initial scour depth; t is the cumulated time from the beginning of the storage depletion; $\Delta\sqrt{t}$ is the difference of the square roots of successive cumulated scour times from the beginning of the storage depletion; and the rest of the variables are as defined in section 3.9 and sub-sections 4.4.2 and 5.2.4.

One important structural difference between Eq. 7.5 and Eq. 7.6 illustrated in the following sentences is in terms of H_{prev} and H_{init} and the routing periods. Each routing period corresponds to each routing time step. The scour depth at the beginning of each new routing period (H_{prev}) is dynamic (Eq. 7.5), meaning that if there is sediment storage change there will be a new value of H_{prev} at the beginning of each new routing period. This differs from H_{init} used in Eq. 7.6 that remains constant throughout all the routing periods. The routing period ($\Delta\sqrt{t}$) in Eq. 7.5 is the difference of square roots of successive integrated times (each integrated time is the sum of all the routing times since the beginning of routing). This differs from the square root of the integrated time since the beginning of routing ($\sqrt{t}$) in Eq. 7.6.

Since storage depletion experiments were done with the pool filled with sediment to its full sediment storage capacity, the initial scour depth was therefore equal to zero ($H_{init}=0$). Thus Eq. 7.6 reduces to Eq. 6.24 with $k=0.0040207$. Equation 7.5 and Eq. 6.24 were found to fall on the same storage depletion curve.

Equation 7.5 is more flexible than Eq. 6.24 as it can be used to route sediment both with and without sediment supply unlike Eq. 6.24 that can only be used to describe storage depletion when there is no sediment supply. The form of storage depletion curve that includes sediment supply is:

$$H_{new} = H_{uss} + ((H_{prev} - H_{sup}) - H_{uss}) \exp\left(-k \sqrt{\frac{w}{y_c}} \Delta \sqrt{t}\right) \quad (7.7)$$

where, H_{sup} is as defined in section 3.9.

7.4.3 Application of the translation concept in modelling

Translation is incorporated in the inverted episodic sediment budget model for routing sediment in a series of sediment storage units to account for the lag in sediment arrival times. The translation cells representing the translation reaches in bedrock-controlled rivers are assumed to precede the sediment storage cells. A typical sequence of modelling cells (storage and translation cells) is shown in Fig. 7.4.



Legend: TC-Translation cell; SC-Storage cell; TCL-Translation cell length; Q_{sin} -Sediment supply; Q_{sout} -Sediment output.

Figure 7.4: Sediment storage and sediment translation modelling cells sequence

The translation cell length and the sediment velocity are useful in determining the translation time.

$$T_t = \frac{TCL}{v_s} \quad (7.8)$$

where TCL is the translation cell length, v_s is the sediment velocity and T_t is the translation time.

The translation time has been incorporated into the exponential sediment storage depletion equations (Eqs. 6.24 and 7.7) by adding it to the model time step to generate the sediment routing time. This has been generated by multiplying the exponential sediment depletion rate component $\exp(-k \sqrt{w/y_c} \Delta\sqrt{t})$ by the exponential sediment lag component $\exp(-k \sqrt{wT_t/y_c})$, which simplifies to $\exp(-k \sqrt{w/y_c} (\Delta\sqrt{t} + \sqrt{T_t}))$. The rationale for choosing the exponential lag function $\exp(-k \sqrt{wT_t/y_c})$ has been explained in the following paragraphs.

High scour rate of fine and light sediment particles in upstream cells has been observed experimentally to result in downstream cells filling with sediment at the beginning of the routing time (section 5.7). Similarly the scour rate reduces with time and finally the scour approaches equilibrium at infinite time as the remaining sediment particles in upstream cells become coarser and denser with time resulting in the need for more stream power to scour and move the sediment. This means that during the initial scour time the fine and light scoured sediments move at a much higher velocity in the translation cell than in the subsequent scour times when the sediment is coarser and denser. Thus the sediment is expected to spend less time moving in the translation cell at the beginning than for subsequent scour times. This therefore requires a sediment lag function that accelerates the rate of sediment movement at the beginning than in later scour times for each steady discharge run. The chosen exponential lag component has the potential to do this.

Thus, the chosen exponential lag component can be used to simulate sediment movement out of a translation cell at a higher velocity at the beginning of the time which then reduces to a lower rate and finally ceases as ultimate stable state is achieved in upstream

scouring cell for each steady discharge. The translation lag component has been strictly used in this context to simulate sediment velocity (i.e. the rate of sediment movement) in the translation cell rather than scour rate since the translation cell is a transport reach that does not accumulate sediment.

It is important to note that the solution of the exponential lag component $\exp(-k\sqrt{wT_t/y_c})$ if $T_t=0$ is 1, and as T_t increases the value reduces until it equals zero at equilibrium where $T_t=\infty$. This means the effect of multiplying the exponential lag component by the exponential depletion rate function in routing sediment to downstream cells simulates the lag effect of the translation cell by reducing the depletion rate of the sediments from the upstream cell to the downstream cell. This is equivalent to attenuating the sediment storage depletion rate through lagged sediment routing time.

Following the methods used in Eq. 7.5 and Eq. 7.6 which give the same scour depth, the translation time can be expressed in terms of $\sqrt{T_t}$ or $\Delta\sqrt{T_t}$ depending on the form of the storage depletion equation used. However, the latter form may make the translation concept much more complex as it requires the computation of the square root of the translation time at every time step before computing the time difference between successive time steps. Though the sediment velocity in the translation reach may vary with sediment size and density at short time steps, it is assumed in this study that the major variations can be considered to occur when scour in the upstream cell results in net fill and when it results in net scour. In other words, the model embodies one translation velocity during each downstream cell net fill and another different translation velocity during each downstream cell net scour.

The two forms of the storage depletion equations incorporating the appropriate forms of simulation (routing) time defined in terms of the routing time for the storage cells and translation time are provided in Eq. 7.9 and Eq. 7.10.

$$H_{new} = H_{uss} + ((H_{prev} - H_{sup}) - H_{uss}) \exp(-k\sqrt{\frac{w}{y_c}}(\Delta\sqrt{t} + \sqrt{T_t})) \quad (7.9)$$

$$H_{new} = H_{uss} (1 - \exp(-k \sqrt{\frac{w}{y_c}} (\sqrt{t} + \sqrt{T_t}))) \quad (7.10)$$

where, the variables are as defined before in section 3.9, sub-sections 4.4.2 and 5.2.4 and in this section. It is important to note that if the translation cell length and sediment velocity are known, then T_t should be replaced by TCL/v_s in the storage depletion equations. This is expected to be the case in real river application.

In Eq. 7.9 the sediment simulation (routing) time ($\Delta\sqrt{t} + \sqrt{T_t}$) integrates the storage cell sediment routing time and the immediate upstream translation cell sediment routing time. Similarly, in Eq. 7.10 the sediment simulation time ($\sqrt{t} + \sqrt{T_t}$) integrates the storage cell sediment routing time and the immediate upstream translation cell sediment routing time. The two forms of storage depletion equations (Eq. 7.9 and Eq. 7.10) reasonably approximate the experimentally measured scour depth changes with time in the downstream cells receiving sediment supply from the upstream cells (Figs. 7.10, 7.11, 7.13 and 7.14). Sediment samples of D_{50} of 0.775 mm and 1.15 mm were used both in the model and the experiment. Equation 7.10 applies when the channel or the pool in this case is filled with sediment to its full sediment storage capacity or when it is filled with sediment beyond its full sediment storage capacity. In the latter case, the storage depletion is assumed to start from the top surface of the channel or pool in the current application (where $H_{init}=0$) as explained in sub-section 7.4.1. The alternative form of the storage depletion equation (Eq. 7.10) is Eq. 7.11, which has been developed from Eq. 7.5 by including the translation module. Equations 7.10 and 7.11 are the same as they have both been found to constitute the same storage depletion curve.

$$H_{new} = H_{uss} + (H_{prev} - H_{uss}) \exp(-k \sqrt{\frac{w}{y_c}} (\Delta\sqrt{t} + \sqrt{T_t})) \quad (7.11)$$

Since not all the sediment scoured from the upstream cell is likely to have reached the end of the same upstream cell within the model time step, the supply of all the scoured sediment from the upstream cell to the downstream cell is likely to be an overestimation. The translation time which increases the simulation time (Eq. 7.9 or Eq. 7.10) therefore increases the scour depth in the immediate downstream cell to ensure an appropriate

estimate of sediment storage change to a scour depth that appropriately corresponds to the actual model time step. This therefore moderates the scour depth to account for the fact that by the end of the model time step, less sediment than the theoretically scoured sediment from upstream is likely to have been supplied to the downstream cell.

In applying the translation concept in modelling, the translation time in either Eq. 7.9 or Eq. 7.10 was varied until the inverted episodic sediment budget model results for a steady discharge matched or approximated the experimental results (Figs. 7.14, 7.15, 7.17 and 7.18). This means that the translation time was used as a control variable in the model. The translation time controlled the sediment routing by adjusting the sediment routing time. Refinement of this modelling concept requires the experimental and field determination of the sediment velocities for sediments of different particle sizes and particle densities.

The inverted episodic sediment budget model (Fig. F1 and Code G1) has been built to account for net fill and net scour observed experimentally on pools that were both filling and scouring (Figs. 7.14, 7.15, 7.17 and 7.18). Accounting for net fill required a very small translation time. This is because the large volume of fine and light sediment eroded from the immediate upstream cell had relatively high sediment velocity and therefore most of them moved relatively quickly into the downstream cell thus reducing the lag time. The relatively small sediment routing time results in a relatively big computed value of the exponential component of the storage depletion equations (Eq. 7.9 and Eq. 7.10). The resulting scour depth is thus relatively small. The net fill is shown in the downstream cells within the first hour of each experiment (Figs. 7.14, 7.15, 7.17 and 7.18). Accounting for net scour requires a large translation time as the coarse and dense sediment particles have low velocity of transport and if the translation cell length is the same as that for the fine and light sediment particles, it takes relatively longer to move coarse and dense sediment particles. The net scour is shown in Figs. 7.14, 7.15, 7.17 and 7.18 in times later than the net fill time. The translation times used to adjust the model scour depth changes with time to nearly reproduce the experimental scour depth changes with time for subsequent pools are provided in Table. 7.1.

Table 7.1: Inverted episodic sediment budget model translation times

D ₅₀ (mm)	Net fill translation time for pool 2 (seconds)	Net scour translation time for pool 2 (mins.)	Net fill translation time for pool 3 (seconds)	Net scour time for pool 3 (mins.)
0.775	3.8	12.8	3.8	28.8
1.15	27.8	5.6	27.8	13.9

The small net fill translation time in the order of seconds with both sediments with D₅₀ of 0.775 mm and 1.15 mm (Table 7.1) confirm that the sediment scoured from the immediate upstream cell within the first hour of the experiment are fine and light sediments of relatively high velocity. This means that during the net fill time, most of the sediment scoured in the upstream cell are transferred to the immediate downstream cell within the experimental time step. This is in line with the expectation, as fine and light non-cohesive sediments tend to move at a velocity approaching that of the flow, especially if they are lifted above the bed.

The significant lag or net scour translation time in the order of minutes with both sediment samples with D₅₀ of 0.775 mm and 1.15 mm (Table 7.1) confirms that the sediment scoured from the immediate upstream pool are coarse and dense and therefore of low velocity. Thus there is significant lag in time before all the scoured upstream sediments can be translated to the immediate downstream cell. Since there already would have been fine sediments supplied to the downstream cell during the net fill time, more sediment would therefore be scoured in the downstream cell over the same model time step. This results in net scour.

One interesting feature of the net fill model translation times is that the fine sediment particles with D₅₀ of 0.775 mm translate faster than the coarse sediment particles with D₅₀ of 1.15 mm. This confirms the fact that fine and light sediments move faster than coarse and dense sediment particles. However, this rule does not hold with net scour translation times. There are many possible reasons for this including particle packing, particle orientation, armouring and experimental errors among others discussed in section 5.3.

Since the translation concept is meant to account for the lag in sediment supply (or sediment movement) particularly from external sources or from an upstream cell to a downstream cell, it is important to clearly demarcate the storage depletion equations that apply to different sediment supply scenarios. Thus if there is no sediment supply from external sources and/or upstream cells, the storage depletion curve (Eq. 7.5 or Eq. 6.24) is sufficient for routing sediment in storage units of bedrock-controlled rivers. Equation 7.5 would be applicable if scour potential exists but the available sediment does not exceed the full sediment storage capacity of the channel. Equation 6.24 would be applicable if there is scour potential and the channel is initially filled to its full channel sediment storage capacity or the available sediment exceeds its channel sediment storage capacity. If the scour potential exists and there is sediment supply from external sources and/or upstream sediment storage cells, the appropriate sediment storage depletion equation including translation module provided Eq. 7.9 and Eq. 7.10 applies in routing sediment in storage units of bedrock-controlled rivers. The appropriate sediment storage depletion equation depends on whether the channel is filled with sediment to its full sediment storage capacity, the channel's full sediment storage capacity is exceeded or the channel's full sediment storage capacity is neither equalled nor exceeded.

7.4.4 Treatment of sediment supply in the model

Erosion and deposition are treated in the model in terms of the scour depth changes, but the sediment leaving each upstream cell of the model is moved in volumetric form to subsequent downstream cells. Thus computing scour depth changes by the model requires that the volume of sediment supplied be converted to sediment supply depth before computation. The scour depth is subsequently converted back to volumetric form before moving it to the immediate downstream cell. This requires that the cross-sectional area of the channel or cell that would be occupied by the sediment supplied and the cross-sectional area of the scoured layer of sediment be known.

Since the inverted episodic sediment budget model is built on the assumption that erosion and deposition occur in trapezoidal layers on a rectangular channel with a vertical weir

constituting the down slope edge, the sediment supply is also treated in a similar manner (Fig. 7.5). If the volume of the incoming sediment supply (V_{sup}) at any time t , reduces the scour depth from H_{t-1} to H'_t and increases the lengths of the trapezoidal layer of sediment supply from L_{t-1} to L'_t (Fig. 7.5), then:

$$V_{\text{sup}} = \frac{1}{2}(L'_t + L_{t-1})b(H_{t-1} - H'_t) \quad (7.12)$$

It is important to note that H'_t is the scour depth that corresponds to a temporary sediment storage state over the modelling time step just before instantaneous routing if scour potential exists but is the same as the fill scour depth in the deposition phase. In a more simplified form, H'_t is the same as $H_{\text{prev}} - H_{\text{sup}}$, where H_{prev} as defined in section 3.9 is the scour depth of the channel before the sediment supply depth (H_{sup}) enters. Similarly, H_{t-1} is the same as H_{prev} . Since H_{sup} is unknown, H'_t and L'_t in Eq. 7.12 are unknowns. This requires that Eq. 7.12 be simplified and expressed in terms of only one of these two unknowns.

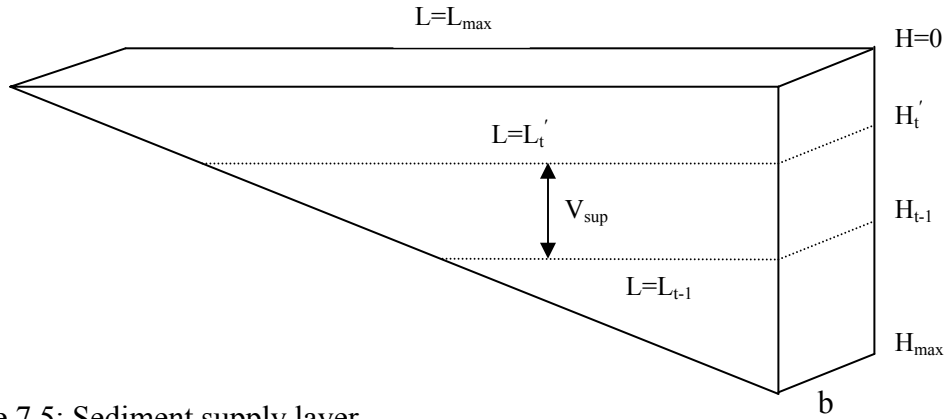


Figure 7.5: Sediment supply layer

From similarity of triangles,

$$\frac{L'_t}{H_{\text{max}} - H'_t} = \frac{L_{\text{max}}}{H_{\text{max}}} \quad (7.13)$$

Making H'_t the subject of Eq. (7.13) gives:

$$H'_t = H_{\text{max}} \left(1 - \frac{L'_t}{L_{\text{max}}}\right) \quad (7.14)$$

Substituting Eq. 7.14 for H_t' in Eq. 7.12 gives:

$$\frac{1}{2}b(L_{t-1} + L_t')(H_{t-1} - H_{\max}(1 - \frac{L_t'}{L_{\max}})) = V_{\text{sup}} \quad (7.15)$$

Equation 7.15 simplifies to Eq. 7.16.

$$\frac{H_{\max}}{L_{\max}}(L_t')^2 + (L_{t-1}\frac{H_{\max}}{L_{\max}} + H_{t-1} - H_{\max})L_t' + (L_{t-1}H_{t-1} - H_{\max}L_{t-1} - \frac{2V_{\text{sup}}}{b}) = 0 \quad (7.16)$$

Equation 7.16 is a quadratic equation in the form given below and with only L_t' as the unknown to be solved for.

$$a(L_t')^2 + c^*L_t' + d^* = 0 \quad (7.17)$$

Comparing Eq. 7.16 and Eq. 7.17 gives a , c^* and d^* as provided in Eq. 7.18, Eq. 7.19 and Eq. 7.20 respectively.

$$a = \frac{H_{\max}}{L_{\max}} \quad (7.18)$$

$$c^* = L_{t-1}\frac{H_{\max}}{L_{\max}} + H_{t-1} - H_{\max} \quad (7.19)$$

$$d^* = L_{t-1}H_{t-1} - H_{\max}L_{t-1} - \frac{2V_{\text{sup}}}{b} \quad (7.20)$$

Only the positive value of the discriminant (i.e. $((c^*)^2 - 4ad^*) > 0$) is computed in the quadratic solution for the longitudinal length of the sediment that corresponds to the temporary sediment storage state (L_t'). This is because only the positive root of the quadratic solution equation (Eq. 7.21) gives the positive length of the sediment in the sediment storage channel at time t .

$$L_t' = \frac{-c^* \pm \sqrt{(c^*)^2 - 4ad^*}}{2a} \quad (7.21)$$

Provided the length of the sediment storage unit ($L_{\max}$), the weir height ($H_{\max}$), the scour depth before the supply enters ($H_{t-1}=H_{\text{prev}}$), the volume of sediment supplied (V_{sup}), the width of the channel (b) and the sediment length before the supply enters (L_{t-1}) are known

then L_t' can be computed. The longitudinal sediment length before the supply enters (L_{t-1}) can be computed from similarity of triangles (Fig. 7.5; Eq. 7.22).

$$\frac{L_{t-1}}{H_{\max} - H_{t-1}} = \frac{L_{\max}}{H_{\max}} \quad (7.22)$$

Equation 7.22 simplifies to Eq. 7.23 used to compute the longitudinal sediment length before the sediment supply enters (L_{t-1}).

$$L_{t-1} = L_{\max} \left(1 - \frac{H_{t-1}}{H_{\max}}\right) \quad (7.23)$$

The effective longitudinal sediment supply length (L_{eff}') for converting the sediment supplied to the sediment supply depth in the model is the average of L_{t-1} and L_t' (see Eq. 7.12).

Equation 7.12 is then simplified to the form show below and used to compute H_t' .

$$H_t' = H_{t-1} - \frac{2V_{\text{sup}}}{b(L_t' + L_{t-1})} \quad (7.24)$$

The computation of the scour depth changes using the inverted episodic sediment budget model results in the actual sediment scour depth (H_t), which has a corresponding sediment length (L_t) in the longitudinal sediment storage unit (Fig. 7.6). In other words, the temporary sediment scour depth ($H_t' = H_{\text{prev}} - H_{\text{sup}}$) becomes the actual scour depth (H_t) after routing. The latter condition applies to erosion. In case of deposition, the temporary state of sediment storage coincides with the routed state.

Application of similarity of triangles on Fig. 7.6 can be used to find the actual longitudinal length of sediment storage at time t (L_t) (Eq. 7.25).

$$L_t = L_{\max} \left(1 - \frac{H_t}{H_{\max}}\right) \quad (7.25)$$

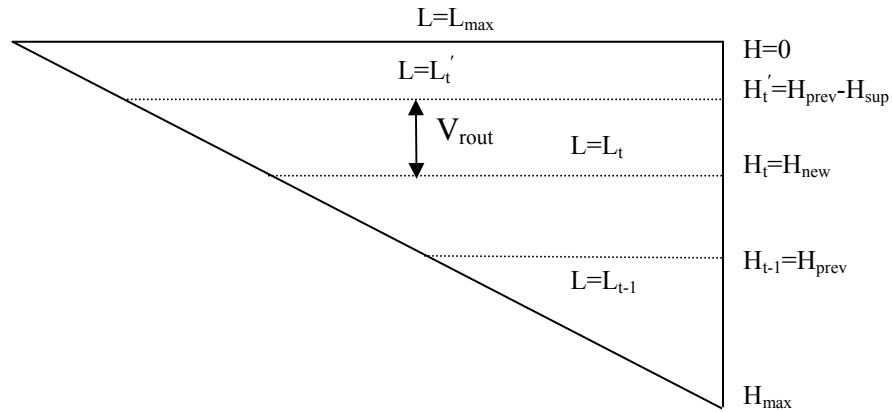


Figure 7.6: Temporary and actual states of sediment routing

The effective longitudinal sediment scour length (L_{eff}) for converting sediment scour depth computed by the model to sediment output volume (V_{rout}) in the trapezoidal layer is the average of L_t' and L_t on routing from the temporary sediment storage state (H_t') to actual sediment scour depth (H_t).

7.5 Model results and experimental confirmation

7.5.1 Temporal sediment storage changes with and without sediment supply

The model results for a single pool upstream of a weir in contracted flume width of 100 mm, length 6.38 m and initially filled with sediment ($D_{50}=0.775$ mm) and experimental confirmation are presented in Figs. 7.7-7.10. Further details of the experimental results corresponding to the model conditions are available in sections 5.4 and 5.6.

The model and experimental results (Figs. 7.7-7.10) are aimed at showing that:

- (i) The H_{uss} and the storage depletion curve concepts for steady discharges derived at a given width (full width of flume of 380 mm) are applicable at a different width (contracted width of flume of 100 mm).

- (ii) The inverted episodic sediment budget model based on H_{uss} and storage depletion curve for each steady discharge, scour depth corresponding to sediment available in the channel, sediment supply and/or translation module (sub-section 7.5.2) simulates the storage depletion curve and ultimate stable storage associated with each steady sediment supply rate.
- (iii) The sediment storage depletion occurs along a storage depletion curve towards specific H_{uss} for each steady discharge regardless of the initial sediment storage in the channel.

Similar trend of sediment storage depletion towards ultimate stable sediment storage exhibited by both the model and experimental confirmation results (Fig. 7.7) validate the use of the H_{uss} and storage depletion curve concepts derived at a width of 380 mm at another width (100 mm in the current case). This shows that the inverted episodic sediment budget model concepts of H_{uss} and storage depletion curve are sound for application at different spatial scales (i.e. smaller and larger systems). However, the scaling requirements will still have to be met unless the interest is on directional change (explained in section 3.7). The method would also need to be tested at field scale to fully establish its sensitivity to scale.

The measured scour depths with time generally exceeded the model estimations and those in the neighbourhood of H_{uss} also exceeded it (Fig. 7.7). The latter can be explained as follows. Since the contracted flume width of 100 mm is small the wall effect may have been more pronounced with more sediment particles attracted laterally towards the wall unlike for the relatively large flume width conditions (380 mm) under which the H_{uss} parameters were derived. This might have reduced the scour depth in the immediate vicinity of the wall and increased the scour depth in the centre of the flume where scour depth measurements were made. The deviations in the experimental and model scour depths may also be viewed as a scale effect since the H_{uss} and storage depletion parameters were derived for the same relatively large flume width (380 mm). The scale effect may be minimized by performing the verification experiments and experiments for deriving dimensionless forms of H_{uss} and storage depletion curve at the same flume

width. This, however, may not be a strong reason as experimental verification and model results produced at the same full flume width of 380-mm with the same sediment sample with D_{50} of 0.775 mm (Fig. 7.16) showed nearly similar behaviour. The steady discharge of 2.85 l/s used in the experiment was relatively high for the small flume width (100-mm) and thus could possibly have contributed to accelerated scour and movement of the fine sediment particles in the sample resulting in increased scour depth.

The model and experimental results with sediment supply and after the supply had been stopped follow similar trends with slight deviations in scour depth magnitude (Figs. 7.8-7.10). The over-measurement of scour depth near and/or at the ultimate stable storage associated with sediment supply (Fig. 7.8) may be due to the same reasons speculated in the preceding paragraph. The slight fluctuations in measured scour depths (Figs. 7.9 and 7.10) may be attributed to fluctuations in the belt sediment feed as explained in section 5.4. In general, the experimental scour depth changes with time clearly validate the potential of the H_{uss} and storage depletion curve model for a given steady discharge to simulate the storage depletion and the ultimate stable storage associated with each sediment supply rate.

The model results reasonably simulate the trend of experimental results after stopping the sediment supply (Figs. 7.8-7.10) within limits of experimental errors speculated in the preceding paragraphs. The deviations are, however, peculiar in the first few hours of stopping the sediment supply. This is because the measured scour depths have tended to exceed the model scour depths for cases with no sediment supply (e.g. Figs. 7.7 and 7.16). However, in the current case, the model scour depths exceed the experimental scour depths in the first few hours after stopping the sediment supply (Figs. 7.8-7.10). The deviations can be explained in terms of the different arrival times to the end of the pool of the sediment particles of different sizes and densities. Though the feeding had been stopped, in the first few hours, the coarse and the dense sediment particles supplied from the feeder were still moving slowly towards the downstream weir and hence contributing to reduced measured scour depths.

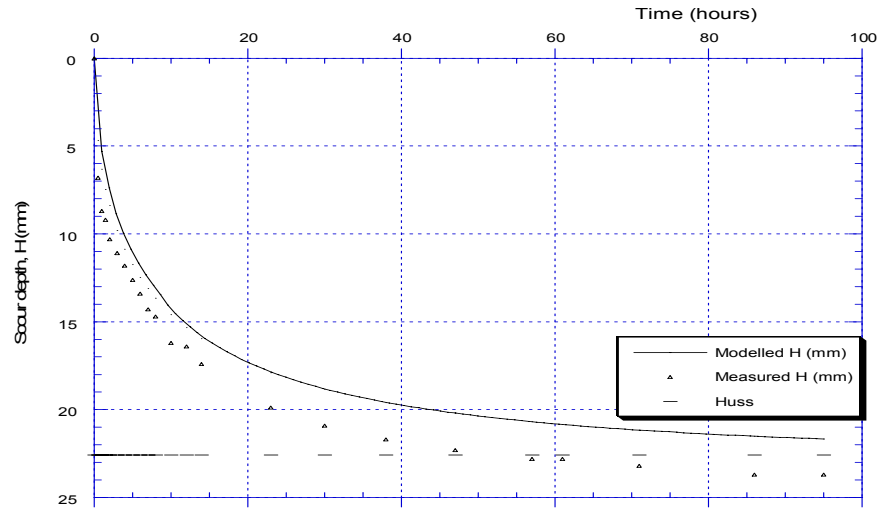


Figure 7.7: Scour depth-time relationship for a steady discharge ($Q=2.85$ l/s) in a flume of 100 mm width initially filled with sediment sample of D_{50} of 0.775 mm and with no sediment supply

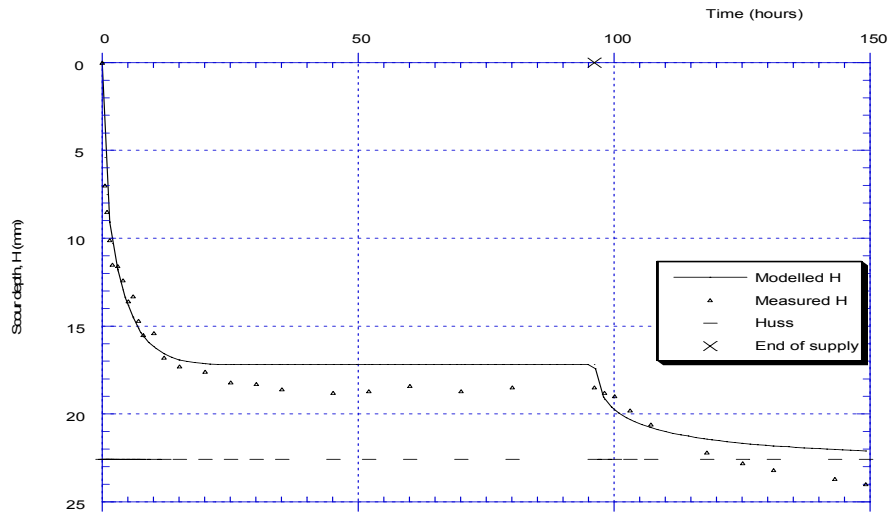


Figure 7.8: Scour depth-time relationship for a steady discharge ($Q=2.85$ l/s) in a flume of 100 mm width initially filled with sediment sample with D_{50} of 0.775 mm and supplied with sediment at a steady rate of 1.8 ml/min for 96 hours and 10 minutes

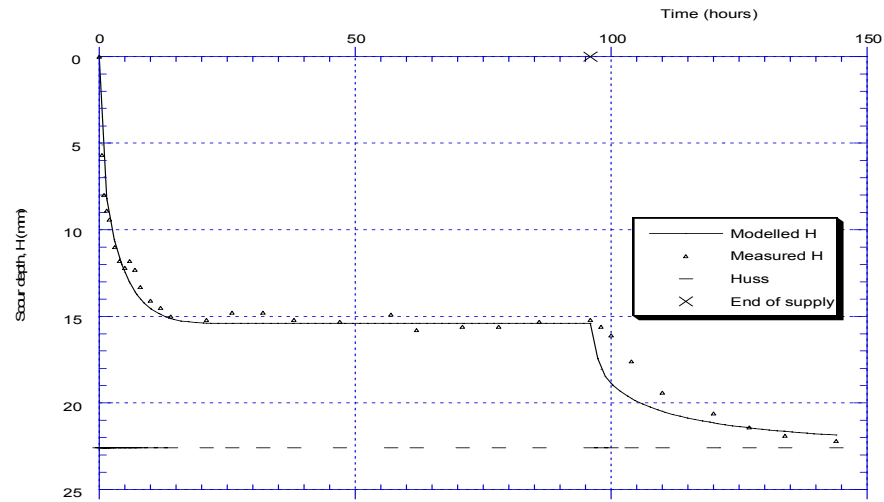


Figure 7.9: Scour depth-time relationship for a steady discharge ($Q=2.85$ l/s) in a flume of 100 mm width initially filled with sediment sample with D_{50} of 0.775 mm and supplied with sediment at a steady rate of 2.5 ml/min for 96 hours

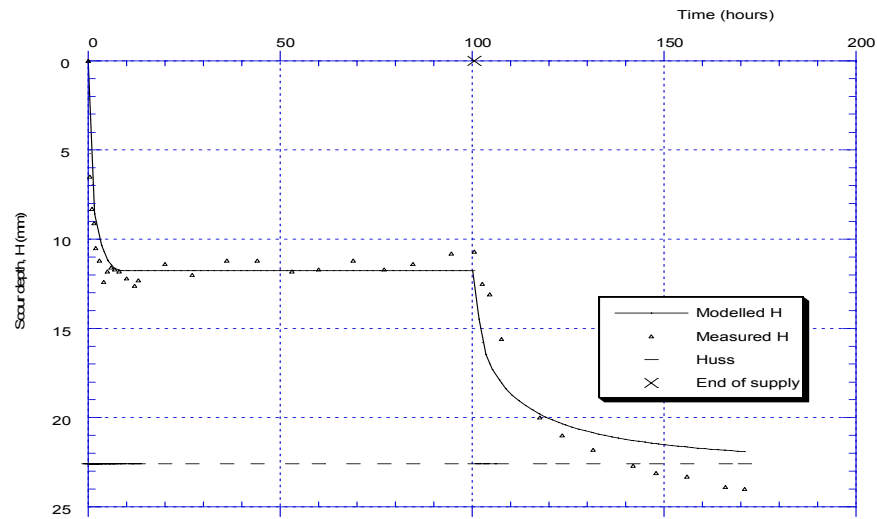


Figure 7.10: Scour depth-time relationship for a steady discharge ($Q=2.85$ l/s) in a flume of 100 mm width initially filled with sediment sample with D_{50} of 0.775 mm and supplied with sediment at a steady rate of 7.3 ml/min for 100 hours and 35 minutes

7.5.2 Temporal sediment storage changes for a series of steady discharges

The temporal experimental sediment storage changes for a series of steady discharges (Tables D1-D21) have been reasonably simulated by the model results with and without sediment supply (Fig. 7.11 and Fig. 7.12). Both the model and the experimental results show that if the steady discharge of 1.73 l/s with a target storage ($H_{uss}=14.75$ mm) is increased to a steady discharge of 3.3 l/s, the scour trajectory immediately changes towards the new target storage ($H_{uss}=25.5$ mm). This clearly confirms that each discharge has a unique H_{uss} that it scours sediment towards along its own sediment scour trajectory (storage depletion curve). Thus the validity of one of the specific hypothesis of this thesis stated in subsection 1.5.1 as '*individual discharge episodes erode sediment along a trajectory (storage depletion curve) towards some definable ultimate stable storage state*' is clearly proved.

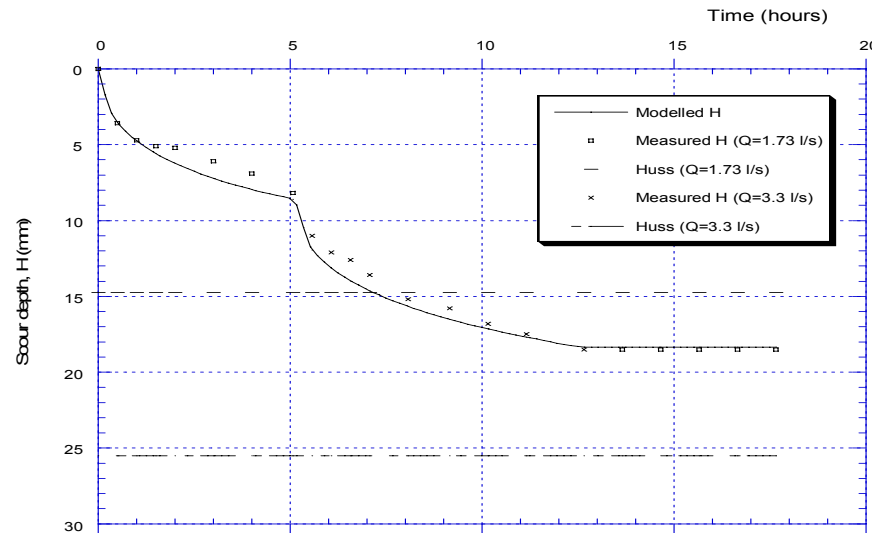


Figure 7.11: Scour depth-time relationship for stepped discharge hydrograph (Fig. 4.11) with no sediment supply

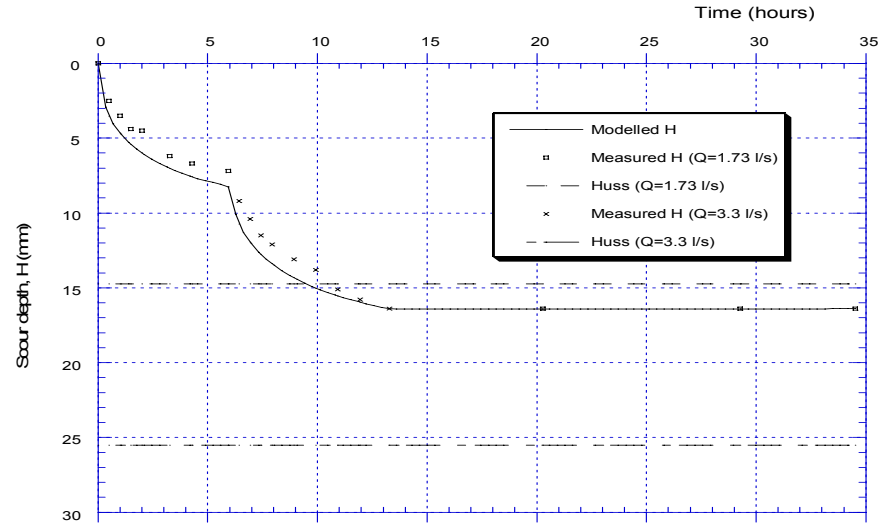


Figure 7.12: Scour depth-time relationship for stepped discharge hydrograph (Fig. 4.12) with steady sediment supply of 1.8 ml/min up to the end of the larger discharge (3.3 l/s)

The model and the experimental temporal sediment storage changes with and without sediment supply (Figs. 7.11 and 7.12) show clearly that if the scour hole is already deeper than H_{uss} of a given discharge then no change in sediment storage occurs. It is important to recall that sediment supply was stopped before finally restoring the discharge to 1.73 l/s from 3.3 l/s in the experimental run with sediment supply. The experimental results therefore validate the sediment routing logic that states that if the scour hole is deeper than the H_{uss} (i.e. $(H_{prev} - H_{sup}) > H_{uss}$) then no scour occurs (section 3.9 and sub-section 7.4.1). This is demonstrated in both cases with and without sediment supply (Figs. 7.11 and 7.12) after the discharge was decreased from 3.3 l/s to 1.73 l/s (Figs. 4.11 and 4.12). It is further confirmed that H_{uss} is the ultimate scour potential of each discharge.

The experimental and the model temporal sediment storage changes illustrate that sediment storage depletion along a trajectory towards the H_{uss} for each specific discharge is independent of the initial sediment storage status before each discharge enters but depends on the discharge magnitude. This is clearly illustrated by the fact that the high discharge of 3.3 l/s entered when the low discharge of 1.73 l/s had already scoured

sediment to a new sediment storage state but it immediately continued to scour sediment along its own scour trajectory towards its H_{uss} . Thus so long as the scour potential is available the sediment storage changes in the channel or pool in this case follow the sediment storage characteristics of individual discharges (i.e. the storage depletion curve and the H_{uss}). The discharge event sequence is, however, important. This is because a big event (3.3 l/s) following a small event (1.73 l/s) that has scoured sediment to a certain storage state still has the potential to scour the sediment while a small event following a big event does not have the potential to scour the sediment. Scour may, however, continue after the discharge decreases provided there is sediment supply that replenishes the potential to scour or the scour potential of the low discharge has not been exceeded. The model as indicated earlier is therefore strongly sediment supply limited. The model thus meets the requirement of bedrock streams that have adequate capacity to transport the sediment but limited sediment supply (Montgomery *et al.*, 1996).

7.5.3 Temporal sediment storage changes for three pools in series

The results of the inverted episodic sediment budget model and their corresponding experimental confirmation results for three pools in series are presented in Figs. 7.13-7.18. The experimental sediment storage changes with time for the series of pools are discussed in section 5.7 and the experimental conditions are summarized in Table 4.3. The initial scour depth for pool 1, which was initially full of sediment was $H_{init}=0$, when either sediment size with D_{50} of 0.775 mm or 1.15 mm were used. The initial scour depths for pools 2 and 3, each of which was initially partially full of sediment were 9.8 mm and 10.8 mm respectively, when sediment size with D_{50} of 0.775 mm was used. When sediment size with D_{50} of 1.15 mm was used in modelling, the initial scour depths of pools 2 and 3 were 6.8 mm and 7 mm respectively. All the values of the initial scour depths given here correspond to the respective initial scour depth values for experimental pools 2 and 3 whose results have been used for validation of the model results.

The modelled scour depth changes with time closely approximated the measured scour depth changes with time for the corresponding model and experimental pools. For the

same discharge of 11.1 litres/sec, the scour depth changes with time for corresponding experimental and model pools followed a similar trend with minor deviations in some instances (Figs. 7.13-7.18).

The measured scour depth changes with time in pool 1 with sediment sample size D_{50} of 0.775 mm are consistently higher than the corresponding modelled scour depth changes with time (Fig. 7.16). This can possibly be explained in terms of sediment size and the depression of the measuring sediment surface by the measuring device. The latter reason may not be contributing to the deviation significantly, as the discharge of 11.1 litres/sec was fairly strong in the experimental flume with a high velocity that had the ability to redistribute the fine sediment from the neighbourhood to the disturbed surface instantly. The sediment size was a strong factor as the lighter sediment may have been scoured faster than the model simulation by the discharge of higher velocity. This is because the model was built from storage depletion curve and H_{uss} integrated over a wide range of sediment sizes including coarse sediments that had smaller values of corresponding scour depths to fine sediments for the same discharge. This means that the model scour depths for fine sediments are likely to be relatively smaller than the measured scour depths. Based on this reasoning, the model scour depths for coarse sediments are likely to be slightly greater than the measured scour depths. This in pool 1 for the coarse sediment size of 1.15 mm only happens at later time steps as the measured scour depth approaches the ultimate stable scour depth (Fig. 7.13). In the earlier time steps (within the first 6 hours) for pool 1 with the coarse sediment sample with D_{50} of 1.15 mm, the measured scour depths exceeded the model scour depths. This changed to a situation where they perfectly marched as time increased before the modelled scour depth exceeded the measured scour depth.

The underprediction of the measured scour depths at the beginning of the simulation time with both the coarse sand ($D_{50}=1.15$ mm) and the fine sand ($D_{50}=0.775$ mm) are likely to be due to measurement errors. The scour depth change with time was more drastic in the earlier hours of the experiments and the measurements were done manually over a number of measuring points with the measurements continuing up to 10 minutes beyond

the demarcated monitoring time. This must have resulted in over-measured scour depths. This can be improved on by automating the measuring equipment so that all the measurements along the longitudinal profile can be taken simultaneously.

The modelled scour depth changes with time and the measured confirmation scour depth changes with time for both the sediment sizes (Figs. 7.13 and 7.16) validate pool 1 as a continuously scouring pool and can therefore be described by a storage depletion curve. Both the model and the experimental results therefore depict pool 1 as a sediment storage reservoir for the downstream pools.

The experimental sediment storage changes with time in the downstream pools (pools 2 and 3 in this case) show net fill and net scour when there is sediment supply from the immediate upstream pool (section 5.7). This is an important consideration when simulating sediment storage changes with time in sediment storage units receiving sediment supply either from external source/s or from the immediate upstream cells.

The modelled net fill and corresponding experimental confirmation scour depth changes with time at the beginning of the simulation and experimental runs respectively in pools 2 and 3 for the same discharge of 11.1 litres/sec and sediment sizes of D_{50} of 1.15 mm and 0.775 mm are clearly plotted in Figs. 7.19-7.22. The explanation for net fill preceding net storage has been provided in section 5.7.

As explained in sub-section 7.5.2, the application of the translation concept formed an integral component for simulating the scour depth changes with time in the downstream cells. Translation made it possible to produce model results for pool 2 that matched the measured results nearly perfectly in two separate simulations each with different sediment sample size of 1.15 mm and 0.775 mm (Figs. 7.14 and 7.17). The same near perfect match occurred for pool 3 with sediment sample size of D_{50} of 1.15 mm (Fig. 7.15) but deviated in magnitude for sediment sample with D_{50} of 0.775 mm (Fig. 7.18). The latter case shows the model overpredicting and underpredicting the measured scour depth within the first 14 hours of net scour and subsequent time respectively. The

deviation over the first 14 hours of net scour may possibly be explained from the fact that the translation time chosen may not be the most appropriate as it overpredicted the scour depth. It may therefore have contributed to the shifting of the model results towards overprediction. However, the translation time associated with net scour was chosen as a compromise to ensure that the model scour depth over the later time steps did not deviate significantly from the measured results.

The near perfect simulation of the measured scour depth changes with time by the model for a series of pools validates the modelling theory developed in this thesis as suitable for modelling sediment dynamics in a series of pools. Furthermore the measured results further validate the fact that sediment storage change with time takes place along the storage depletion curve towards H_{uss} for each discharge and sediment size especially if there is no sediment supply. If there is sediment supply then the volume of sediment supplied, sediment velocity and the sediment size range determines whether there is net fill or net scour towards H_{uss} for each discharge and representative sediment size. Translation is presented as an important simulation tool towards the reproduction of the observed sediment storage change behaviour in each sediment storage unit.

The use of the two different sediment samples with different settling velocities in the two separate sets of experimental runs was aimed at determining the sensitivity of the model results to settling velocity. The similarities in the trends of the model results and the measured confirmation results with both the sediment samples of different D_{50} confirm the working of the modelling principle for different sediment sizes. The model results and the experimental confirmation scour depth changes with time for the different sediment sizes further show the sensitivity of the modelling concept to settling velocity. This is due to the fact that the magnitudes of scour depth changes with time and the H_{uss} for the given discharge in geometrically equivalent pools have been shown to vary with the sediment samples of specific D_{50} (Figs. 7.13-7.18).

It is important to note that when there is no net scour or fill then the river could be in equilibrium with respect to a specific discharge event, there may be no sediment load in

the river or no sediment supply or there could be a lot of sediment in the river but the discharge or stream power has no potential to scour the sediment.

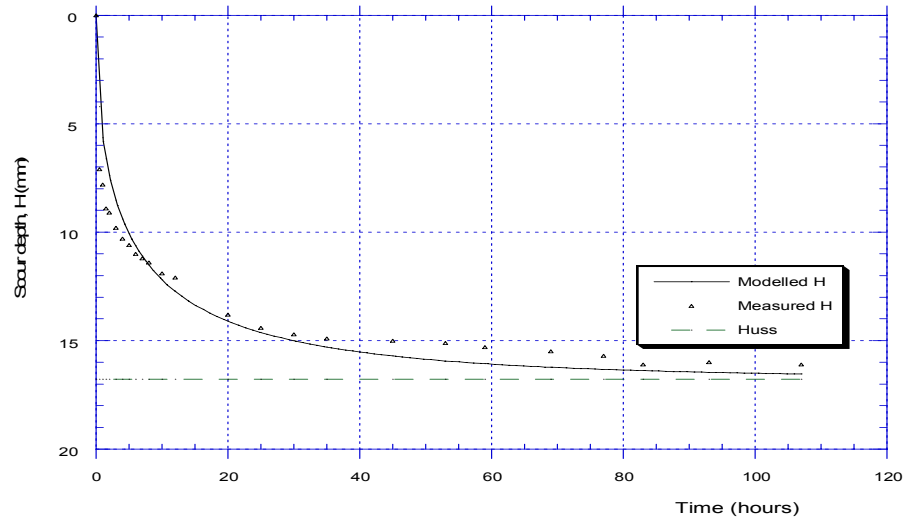


Figure 7.13: Scour depth-time relationship for pool 1 with sediment of D_{50} of 1.15 mm and discharge of 11.1 litres/sec.

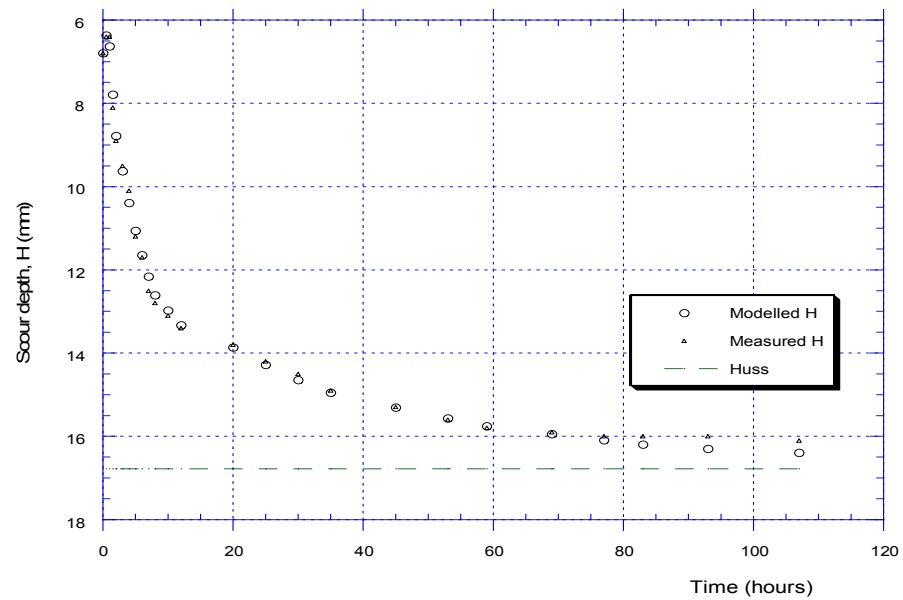


Figure 7.14: Scour depth-time relationship for pool 2 with sediment of D_{50} of 1.15 mm and discharge of 11.1 litres/sec.

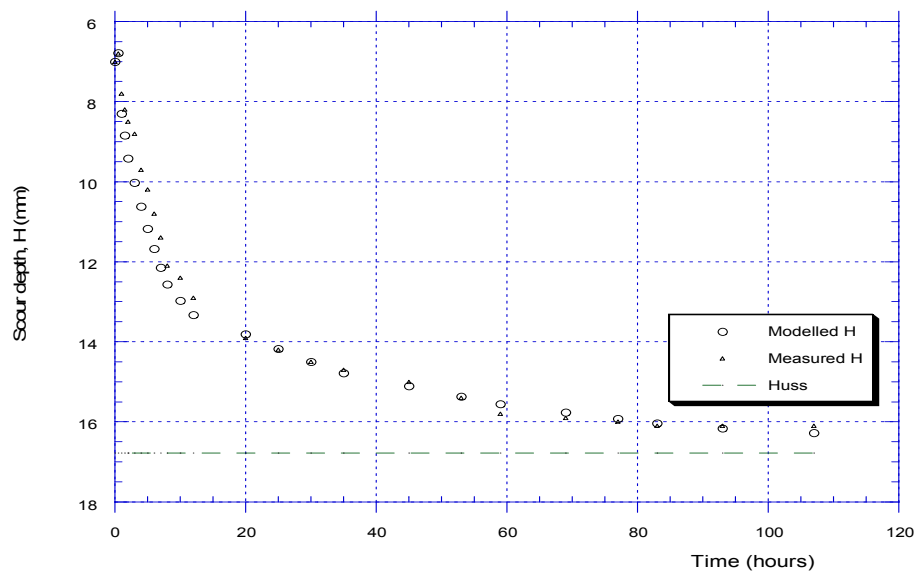


Figure 7.15: Scour depth-time relationship for pool 3 with sediment of D_{50} of 1.15 mm and discharge of 11.1 litres/sec.

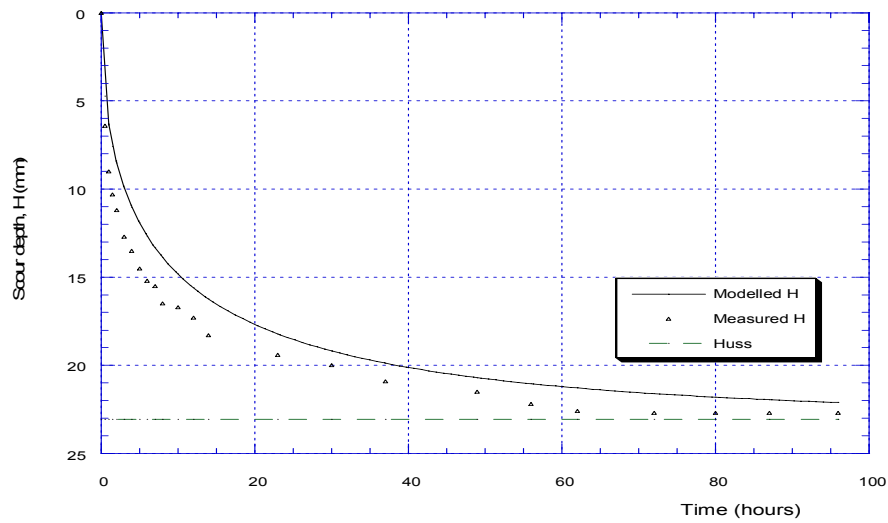


Figure 7.16: Scour depth-time relationship for pool 1 with sediment of D_{50} of 0.775 mm and discharge of 11.1 litres/sec.

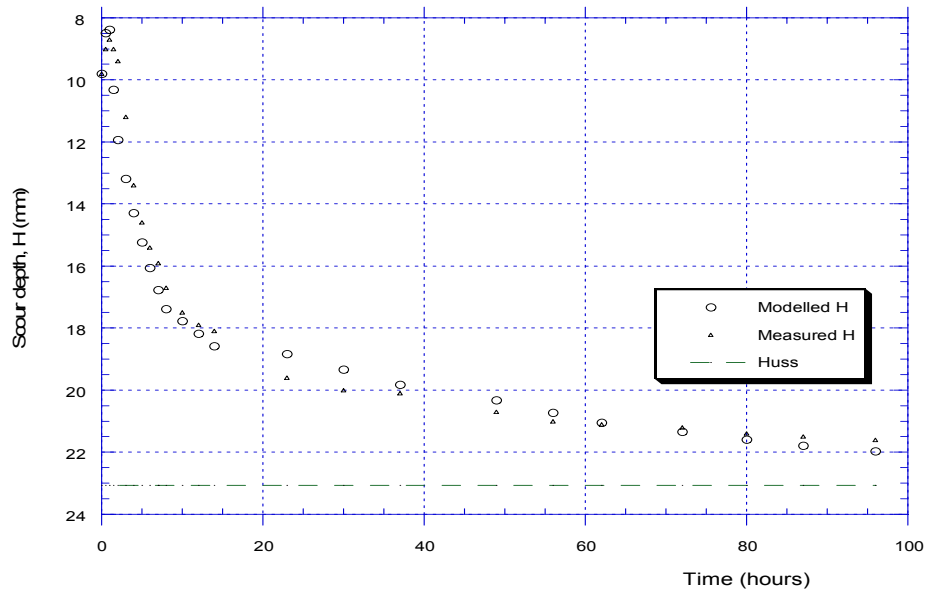


Figure 7.17: Scour depth-time relationship for pool 2 with sediment of D_{50} of 0.775 mm and discharge of 11.1 litres/sec.

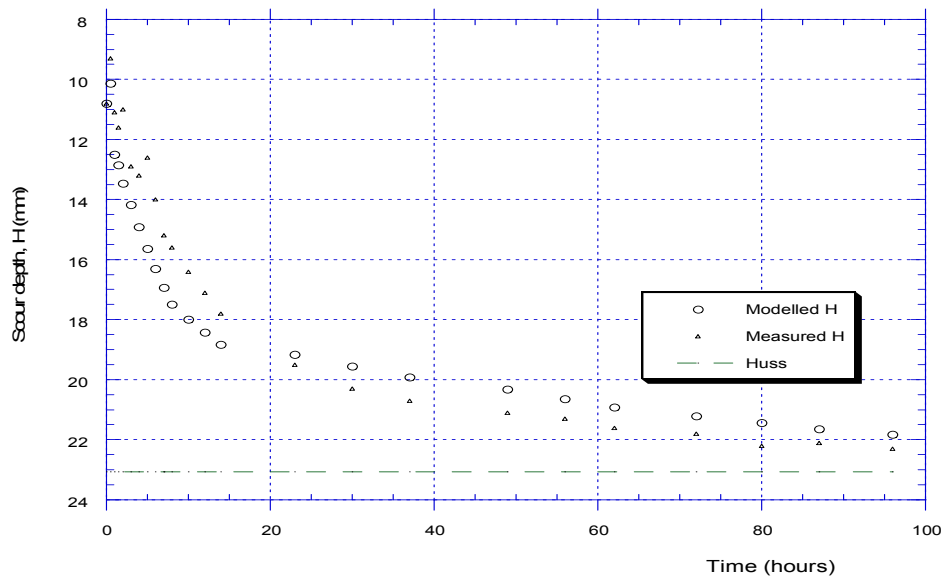


Figure 7.18: Scour depth-time relationship for pool 3 with sediment of D_{50} of 0.775 mm and discharge of 11.1 litres/sec.

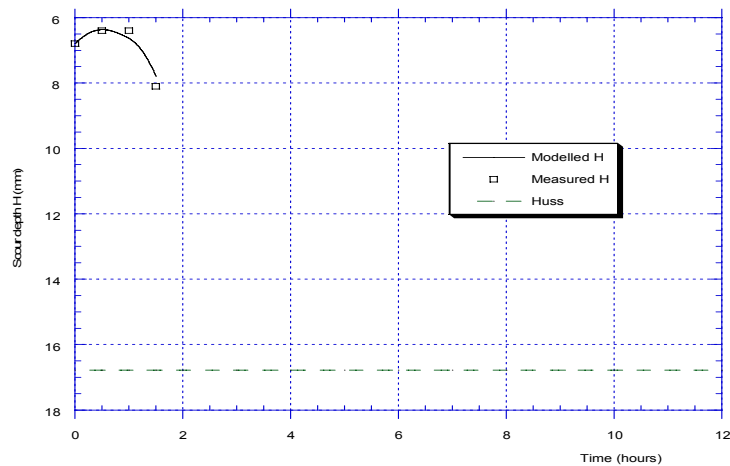


Figure 7.19: Scour depth-time relationship during the first one and a half hours for pool 2 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/sec.

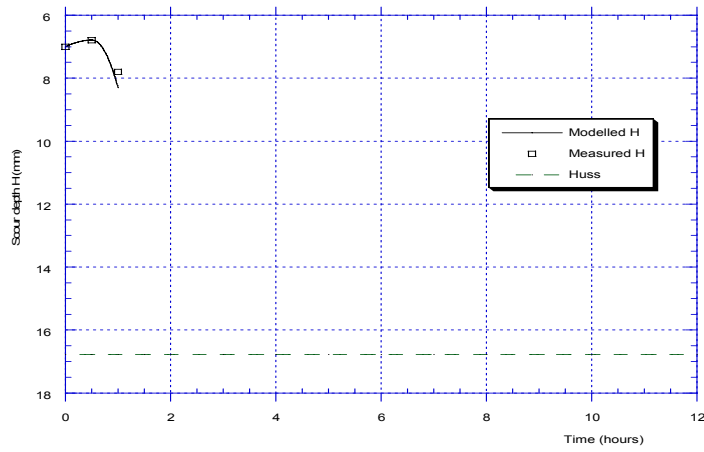


Figure 7.20: Scour depth-time relationship during the first one hour for pool 3 with sediment of D_{50} of 1.15 mm at a steady discharge of 11.1 litres/sec.

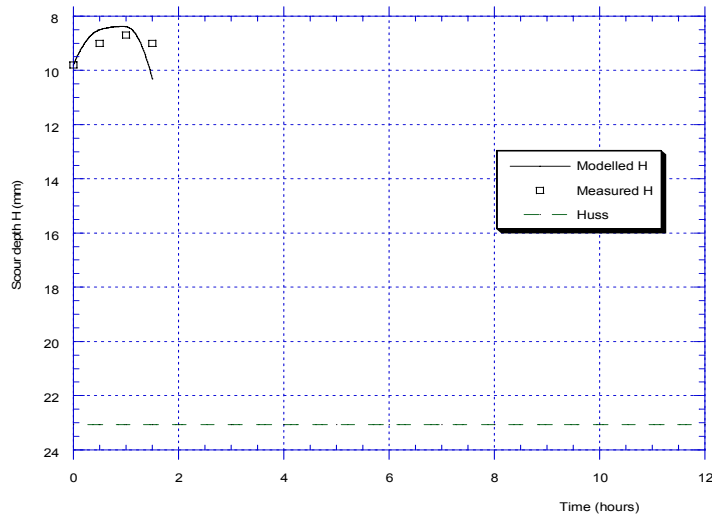


Figure 7.21: Scour depth-time relationship during the first one and a half hours for pool 2 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/sec.

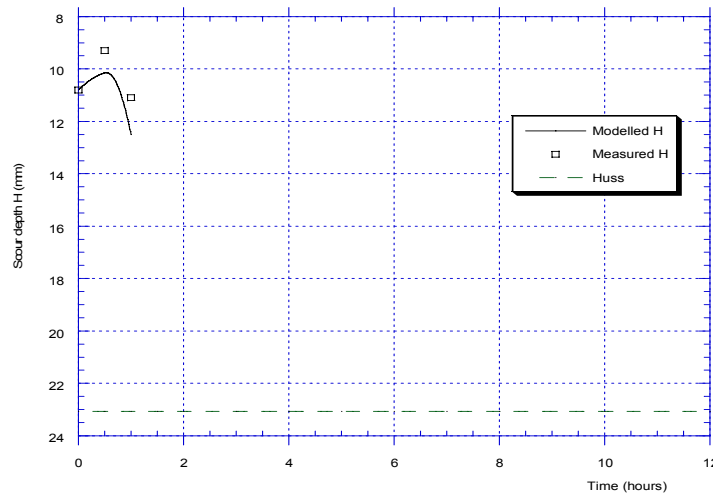


Figure 7.22: Scour depth-time relationship during the first one hour for pool 3 with sediment of D_{50} of 0.775 mm at a steady discharge of 11.1 litres/sec.

7.6 Summary

The inverted episodic sediment budget model has been developed and verified on the basis of laboratory data. The sediment routing is done on the basis of ultimate sediment storage potential of each steady discharge (H_{uss} in the current case) and the scour state corresponding to the sediment available in the sediment storage unit plus the sediment supply ($(H_{prev}-H_{sup})$ in the current case).

The model has been built and verified in terms of scour depths. For any steady discharge that lasts for some time, the ability to scour sediment depends on whether the scour depth corresponding to the sediment available before routing plus sediment supply ($H_{prev}-H_{sup}$) is less than the ultimate sediment storage potential (H_{uss}) for the given steady discharge. If the scour depth corresponding to the available sediment before routing plus the sediment supply ($H_{prev}-H_{sup}$) is less than H_{uss} then scour occurs along a storage depletion curve towards H_{uss} for the given discharge. The model includes different components of

the sediment routing logic for budgeting sediment when scour potential exists. This is done in order to account for the fact that the sediment storage condition in the storage unit can be such that it is filled to capacity, filled beyond capacity or is hardly full of sediment.

If the scour depth corresponding to the available sediment plus sediment supply exceeds the H_{uss} , sediment storage occurs. In this case, a simple mass (volume) balance is built into the model that simply adds the sediment supply to the available scour depth before the current routing time. However, the model accounts for the possibilities of the storage unit getting filled to below, at or above sediment storage capacity.

The inverted episodic sediment budget model has been built to principally route sediment in a series of pools for a given steady discharge that lasts for some time. A translation module has been in-built into the model to account for sediment movement in translation reaches (or sediment transport reaches) or to attenuate sediment storage by increasing the sediment routing time. The increase in sediment routing time ensures that the exponential storage depletion function scours more sediment so as to adjust the sediment scour depth at the end of the model time step. This ensures sediment routing occurs at the appropriate time when all the sediment supplied from upstream within the same time step would have reached the downstream cell.

Translation allows bulk sediment routing as it accounts for the time required for holding sediment at the end of each storage unit before routing takes place in each time step. Translation concept is dependent on sediment velocity, which depends on sediment particle size and density. Translation improves on the efficiency of sediment removal to downstream storage units and at the same time account for the fact that sediment supply and sediment translocation from one location to the other in a given storage unit are not instantaneous processes. In other words, the translation accounts for the lag in sediment supply or movement. The translation time has been used as an important control for adjusting the translation time in order to ensure either net fill or net scour in downstream storage units (pools in the current application). The use of the translation concept made it

possible to almost reproduce perfectly the experimental scour depth changes with time using model simulation in downstream cells (cells 2 and 3).

The dependence of ultimate stable sediment storage on sediment supply has been illustrated. The ultimate stable sediment storage has been found to depend on sediment supply for each steady discharge. In addition to this, the model built on the basis of H_{uss} for each steady discharge has been confirmed to correctly simulate the sediment storage changes with time for different sediment supply rates. The relationship between the dynamic sediment storage above H_{uss} for each discharge that has been referred to as active sediment storage and sediment supply requires further development so that it can be built as an independent module within the inverted episodic sediment budget model. The response of the model to sediment supply changes demonstrates its suitability for routing sediment in bedrock-controlled rivers. This is because bedrock-controlled rivers have been noted to be responsive to sediment supply limitations.

The H_{uss} and storage deletion concepts were further validated through experimental confirmation of model simulation of scour depth changes with time using a series of steady discharges. The results illustrated clearly that the sediment storage changes in the sediment storage unit are responsive to changes in the discharge magnitude. This is because on changing the discharge the storage depletion curve immediately changed (increased rate of scour for increased discharge or reduced rate of scour or no scour for decreased discharge) towards H_{uss} for the new discharge. The results also showed that the discrete discharge characteristics of H_{uss} and storage depletion curve are adhered to regardless of the initial state of sediment availability. Thus the fundamental modelling principles of H_{uss} and storage depletion curves for discrete discharges and their variation with discrete discharge magnitudes are validated. The sediment routing logic in terms of the relationship between the H_{uss} and the scour depth corresponding to sediment initially available in the storage unit plus sediment supply ($H_{prev} - H_{sup}$) has also been further verified. This has been achieved particularly by showing that the discharge that originally had the potential to scour sediment could not scour sediment after a high discharge had scoured it to a scour depth deeper than H_{uss} of the small discharge.

The ability of the inverted episodic sediment budget model to route sediment in a series of storage units characteristic of bedrock-controlled rivers has been demonstrated by using the model to simulate sediment storage changes in three pools in series. The results of the model have been verified experimentally. Both the experimental and the model scour depth changes with time have been found to follow similar scour and/or fill patterns. Pool 1 was found to continuously undergo net scour while pools 2 and 3 filled at the beginning (net fill) and scoured at later time steps towards H_{uss} for the given discharge. Thus pool 1 has been referred to as a net scouring pool that acts as sediment supply reservoir for the downstream pools. Pools 2 and 3, however, undergo both net scour and net fill.

CHAPTER EIGHT

UNSTEADY FLOW INVERTED EPISODIC SEDIMENT BUDGET MODEL

8.1 Preamble

Unit stream power (stream power per unit width or stream power per unit area) driven unsteady flow inverted episodic sediment budget model has been conceptualized and developed in this chapter to route sediment dynamics in a series of pools with a series of rise-peak-fall discharge hydrographs.

The unsteady flow on each limb of each rise-peak-fall hydrograph has been converted to an equivalent steady discharge on that limb by making use of the unit stream power principles and assuming the equivalent steady discharge occurs when the flow is steady and uniform. This was aimed at expressing the unsteady flow in a form that could be applied in the inverted episodic sediment budget model. The latter model has been developed for steady discharges. The model also accounts for non-event periods.

The developed model has been referred to as unsteady flow inverted episodic sediment budget model. The model has been developed in terms of the rising and the falling limbs of the hydrograph to indicate two important energy states that drive a geomorphic system towards high and low energy states respectively. Thus in a sediment dynamics model seeking to differentiate the effects of high-energy state from those of low-energy state the rising limb and the falling limb of the hydrograph become important.

The fundamental modelling principles remain H_{uss} and storage depletion curves except that each rise-peak-fall discharge hydrograph is treated in terms of the idealized rising limb equivalent steady discharge and the idealized falling limb equivalent steady discharge. The method is generally aimed at routing sediment in different morphologic or channel types in bedrock-controlled rivers. The representation of unsteady flow in terms of the equivalent steady discharge using stream power principles is a reasonable method

of modelling since stream power or boundary shear stress conventionally drives sediment hydraulics. Since the flow in rivers is in practice unsteady and the scour and movement of sediment grains are based on stream power or boundary shear stress, a model that uses any of these principles can be considered to be reasonable and theoretically sound.

The study also established the key parameters that affect the bimodal division of each rise-peak-fall hydrograph into rising and falling limbs equivalent steady discharges of given magnitudes.

The hypothetical application of the unsteady flow inverted episodic sediment budget model has been built at the laboratory scale of discharges. Two sediment samples of different D_{50} using the flume scale dimensions as those used in deriving the H_{uss} and the storage depletion curves (model calibration) (Figs. 6.1 and 6.2) have been used. Similar flume dimensions and sediment samples had also been used in verifying the working of the inverted episodic sediment budget model (Fig. F1 and Code G1). Finally, the need for and how to develop dimensionless H_{uss} and storage depletion curves for different sediment storage units (e.g. channel types) found in natural bedrock-controlled rivers such as the Sabie River have also been explained.

8.2 Representation of the spatial units

Each channel or pool has been represented in the model by a single cell of similar characteristics as that described in section 7.2.

8.3 Distribution of unsteady flow into equivalent steady discharges on the rising and the falling limbs of the hydrograph

Unsteady flow has been treated in terms of the equivalent steady discharges on the rising and the falling limbs of the individual rise-peak-fall hydrographs. The time varying flow over the rising and the falling limbs of the hydrograph can be represented by respective representative (equivalent) steady discharges distributed over the entire duration of each

of the limbs of the hydrograph using stream power principles (subsections 8.3.1, 8.3.2 and 8.3.3). Thus the use of the rising and the falling limbs equivalent steady discharges in sediment dynamics modelling is equivalent to driving the unsteady flow model with the stream power in each limb. The theoretical treatment of unsteady flow in terms of equivalent steady discharges is necessary because the inverted episodic sediment budget model uses steady discharges for sediment routing.

An equivalent steady discharge that will do the same amount of work as the unsteady flow on each hydrograph limb of a given duration can be estimated by equating steady discharge unit stream power over its entire duration to unsteady flow unit stream power over the same duration in the same limb (see sub-section 8.3.3).

The single discharge hydrographs with rising and falling limbs have been idealized as triangular shapes, an example of which is shown in Fig. 8.1. The representation of the equivalent steady discharge magnitude over its duration on both the rising limb of the hydrograph and the falling limb of the hydrograph in an idealized single hydrograph with a rising limb and a falling limb is also shown in Fig. 8.1.

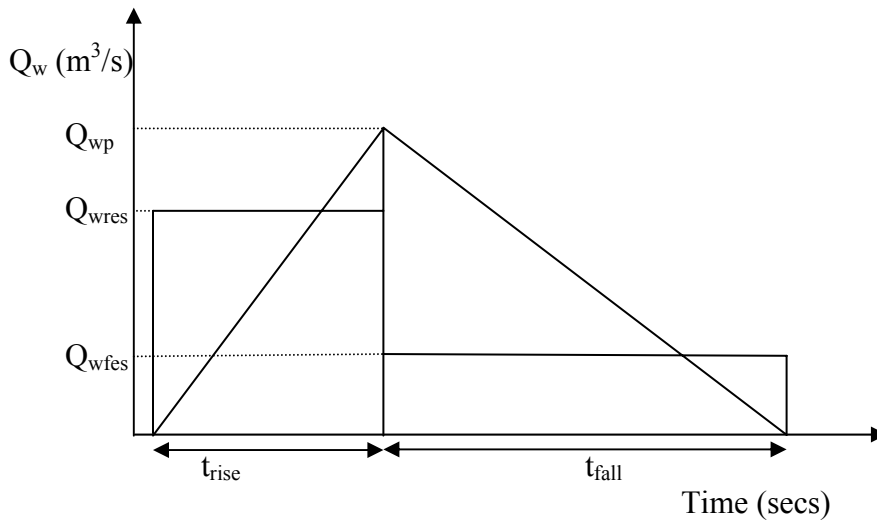


Figure 8.1: Representation of the idealized single hydrograph in terms of the rising and the falling limbs equivalent steady discharges

The model equivalent steady discharge on the rising limb of the hydrograph (Q_{wres}) and the model equivalent steady discharge on the falling limb of the hydrograph (Q_{wfes}) occur

over duration t_{rise} and t_{fall} respectively (Fig. 8.1). Since a flood generally recedes to base flow much slower than rises, the duration of the recessive limb is either equal to or greater than the duration of the rising limb of the hydrograph.

8.3.1 The rationale for representing unsteady flow in terms of the rising and the falling limbs of the hydrograph

Representation of the unsteady flow in terms of the rising and the falling limbs of the discharge hydrograph is considered pragmatic in budgeting sediment dynamics in natural bedrock-controlled rivers using the inverted episodic sediment budget model. This takes cognizance of the differences in sediment transport and storage potentials on the rising and the falling limbs of the hydrograph. The rising limb of the hydrograph, as will be shown in subsection (8.3.2), is a high stream power (or high energy) limb compared to the falling limb and is therefore generally associated with net erosion. This means that the falling limb of the hydrograph is a low stream power (or low energy) limb as compared to the rising limb and is therefore generally associated with net fill or no geomorphic change. The potential to have net fill on the rising limb of the hydrograph and net erosion on the falling limb of the hydrograph also exists and is dependent on the stream power and the sediment storage status of the channel and/or sediment supply.

It is important to emphasize that the falling limb of the hydrograph occurs when the flood has reached its peak flow and loses energy as it recedes to the base flow. However, depending on the magnitude of the receding stream power and the volume of sediment available in the river as explained in the preceding paragraph, the erosion potential may still exist. This justifies the occasional occurrence of sediment scour and movement on the falling limb of the hydrograph.

The use of stream power in evaluating geomorphic change is important as stream power assessments are useful in evaluating sediment discharge within a stream channel and the deposition or erosion of sediments from the streambed (Fischenich, 2001). Sediment

scour and sediment transport increase when unit stream power increases. Unit stream power (ω) is dependent on shear stress (τ) and flow velocity (v) (see Eq. 8.1).

$$\omega = v.\tau = \rho g v h S_e = \frac{\rho g Q_w S_e}{b} \quad (8.1)$$

where h is the hydraulic depth of flow in m, S_e is the energy slope in m/m and all the other variables are as defined before.

The use of the rising limb and the falling limb of the discharge hydrograph accounts for energy slope variations. This is an important aspect of the unsteady flow inverted episodic sediment budget model since the energy slope (S_e) is an important multiple of the unit stream power ($\rho g Q_w S_e / b$).

8.3.2 Mathematical analysis of the energy slope variations on the rising and the falling limbs of the hydrograph

The discharge hydrograph is treated in terms of the rising limb and the falling limb because of the differences in the stream power between the two limbs of the hydrograph as explained in sub-section 8.3.1. This can be demonstrated theoretically through mathematical analysis of the energy slope variations on the two limbs of the hydrograph as follows. Assuming the flow over the rising limb and the falling limb of the hydrograph to be gradually varied unsteady flow, the principle of conservation of the total energy applied to Fig. 8.2 gives the following equation (Eq. (8.2)).

$$z + y + \alpha \frac{v^2}{2g} = z + dz + y + dy + \alpha \frac{v^2}{2g} + d\left(\alpha \frac{v^2}{2g}\right) + \frac{1}{g} \frac{\partial v}{\partial t} dx + S_f dx \quad (8.2)$$

where, z is the vertical distance of the channel bottom above the datum (m); y is the depth of flow (m); α is the energy coefficient; v is the mean velocity of flow through the channel section (m/s); dx is the change in distance in the direction of flow (m); S_f is the friction slope; g is the acceleration due to gravity (m/s^2); t is the time of flow (seconds); dz is the change in the vertical distance of the channel bottom above the datum (m); and dy is the change in the depth of flow (m).

Simplification of Eq. 8.2 results in Eq. 8.3 representing the change in total head.

$$d\left(z + y + \alpha \frac{v^2}{2g}\right) = -S_f dx - \frac{1}{g} \frac{\partial v}{\partial t} dx \quad (8.3)$$

where, $d(z + y + \alpha v^2/2g)$ is the change in total head in metres (m).

Equation (8.3) shows that the change in total head in gradually varied unsteady flow depends on the effects of friction and acceleration (Chow, 1959). Unlike steady flow in which friction is the only energy change if eddy loss is negligible, additional energy change in flow occurs in unsteady flow due to the effect of acceleration emanating from the variation in velocity of flow with time. The total change in head in gradually varied unsteady flow therefore consists of the change in head due to friction ($S_f dx$) and the change in head due to acceleration ($((1/g)(\partial v/\partial t)dx)$). The distribution of these energy change components in unsteady flow is provided in Fig. 8.2.

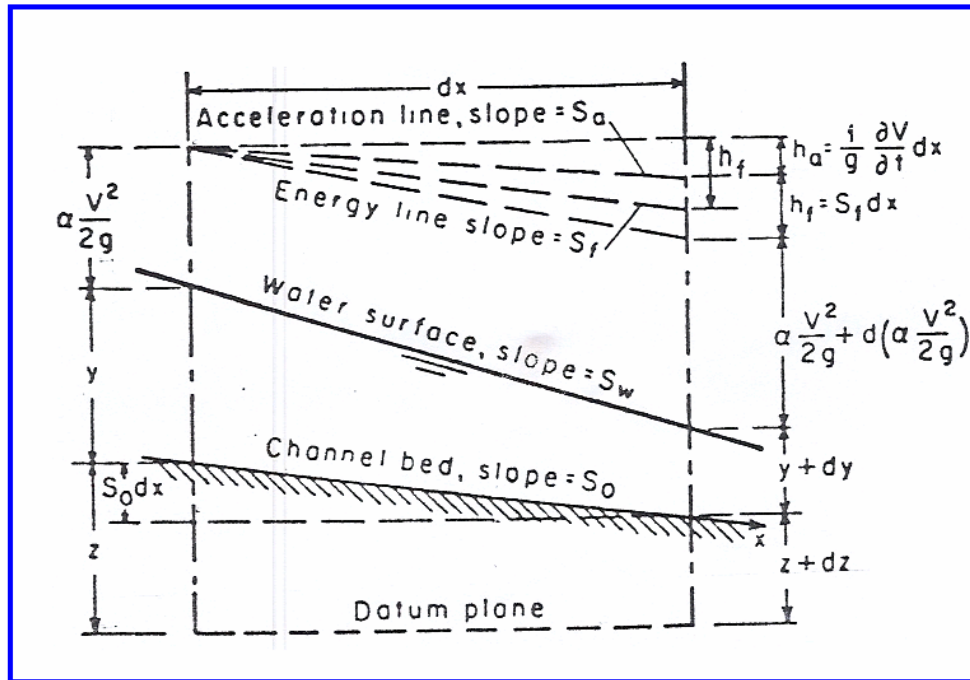


Figure 8.2: Simplified representation of energy in unsteady flow (Source: Chow (1959))

It is important to note that $h_f = S_f dx$ in the extreme right of Fig. 8.2, which is the friction head component in gradually varied unsteady flow is distinct from h_f in the immediate left in the same diagram, which represents the friction head component in gradually varied steady flow.

Simplification of Eq. 8.3 by dividing it by dx and replacing the total derivatives with partial derivatives gives Eq. 8.4. The total derivatives have been replaced by the partial derivatives because the changes in depth and in velocity head may vary with both the time (t) and the distance (x).

$$\frac{\partial H_T}{\partial x} = \frac{\partial \left(z + y + \alpha \frac{v^2}{2g} \right)}{\partial x} = -S_f - \frac{1}{g} \frac{\partial v}{\partial t} \quad (8.4)$$

where, H_T is the total head (energy) (in m). This equation (Eq. 8.4) clearly shows that the total energy slope ($-\partial H_T / \partial x$) is the sum of the friction slope and the acceleration slope, which is associated with the unsteadiness.

From Eq. 8.4 and assuming the energy coefficient (α) to be unity as has been the conventional practice, the total energy (H_T) is given by Eq. 8.5.

$$H_T = z + y + \frac{v^2}{2g} \quad (8.5)$$

On partial differentiation with respect to x , Eq. 8.5 gives Eq. 8.6.

$$\frac{\partial H_T}{\partial x} = \frac{\partial z}{\partial x} + \frac{\partial y}{\partial x} + \frac{v}{g} \frac{\partial v}{\partial x} \quad (8.6)$$

Substituting the bed slope (S_0) for $-\partial z / \partial x$ since $S_0 = -\partial z / \partial x$ in Eq. 8.6 results in Eq. 8.7.

$$\frac{\partial H_T}{\partial x} = -S_0 + \frac{\partial y}{\partial x} + \frac{v}{g} \frac{\partial v}{\partial x} \quad (8.7)$$

Equating Eqs. 8.4 and 8.7 and replacing the friction slope (S_f) with the energy slope (S_e) results in Eq. 8.8. The friction slope (S_f) as shown in Fig. 8.1 and Eqs. 8.2-8.4 is assumed to be the same as the energy slope (S_e).

$$S_e = S_0 - \frac{\partial y}{\partial x} - \frac{v}{g} \frac{\partial v}{\partial x} - \frac{1}{g} \frac{\partial v}{\partial t} \quad (8.8)$$

This equation (Eq. 8.8) describes the general expression for the energy slope in unsteady, non-uniform flow equation. The four terms on the right of Eq. 8.8 represent the component slopes which produce the variable energy slope S_e due to changing discharge

(Fread, 1975). The terms S_0 , $\frac{\partial y}{\partial x}$, $\frac{v}{g} \frac{\partial v}{\partial x}$ and $\frac{1}{g} \frac{\partial v}{\partial t}$ represent gravity force, pressure force, convective (spatial) acceleration and local (temporal) acceleration respectively.

Since discharge increases with time on the rising limb of the discharge hydrograph, there is corresponding increase in velocity with time resulting in positive acceleration. However, on the falling limb of the hydrograph, the discharge decreases with time with a corresponding decrease in velocity with time thus resulting in negative acceleration (deceleration). Thus, flow deceleration occurs on the falling limb of the hydrograph, making both the convective and local acceleration negative. Consideration of this in Eq. 8.8 results in energy slope on the falling limb of the hydrograph being given by Eq. 8.10. Thus the energy slope on the rising limb of the hydrograph (S_{er}) is given by Eq. (8.9) while that on the falling limb of the hydrograph (S_{ef}) is given by Eq. (8.10).

$$S_{er} = S_0 - \frac{\partial y}{\partial x} - \frac{v}{g} \frac{\partial v}{\partial x} - \frac{1}{g} \frac{\partial v}{\partial t} \quad (8.9)$$

$$S_{ef} = S_0 - \frac{\partial y}{\partial x} + \frac{v}{g} \frac{\partial v}{\partial x} + \frac{1}{g} \frac{\partial v}{\partial t} \quad (8.10)$$

The energy gradient on the rising limb of the hydrograph (Eq. 8.9) is thus theoretically greater than the energy gradient on the falling limb of the hydrograph (Eq. 8.10). This means that the stream power on the rising limb of the hydrograph is greater than the stream power on the falling limb of the hydrograph for any given rise-peak-fall discharge hydrograph and channel geometry. This is because the variation in the stream power is directly dependent on the variation in the energy gradient.

8.3.3 Distribution of flow on the rising and the falling limbs of the hydrograph using unsteady flow analysis

Changing discharge magnitudes with time in any discharge hydrograph cause variable water surface slopes and accelerations of unsteady, non-uniform flow, and thus result in variable energy slopes. The effects of changing discharge can produce a 'loop' in the stage-discharge rating curve such that two different stages exist for each discharge. The

lesser stage is associated with the rising limb of the discharge hydrograph while the greater stage occurs during the recessive limb of the hydrograph.

A loop-rating curve is one that has a different stage-discharge relationship when the river level is rising than when it is falling (Fig. 8.3). The loop is a manifestation of a hysteresis effect resulting from the variable energy slope associated with the dynamic inertia and pressure forces of unsteady flood discharge (Fread, 1975).

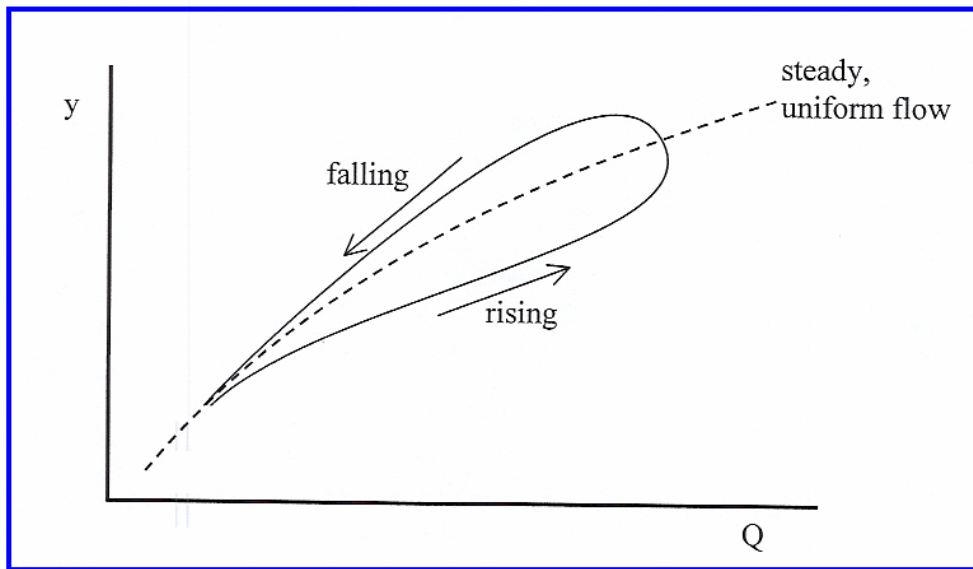


Figure 8.3: An example of a loop-rating curve

A study on flood hydrographs in open channels by Graf and Qu (2004) has clearly shown that peak stage does not coincide with peak flow for unsteady flows. The peak flow always precedes the peak stage. This phenomenon, the looped rating curve effect, as has been discussed above results from changes in energy slope. The change in slope can be caused by the backwater from a bedrock-control in this study or by the dynamics of the flood wave. Backwater affects outflow and storage, and flow dynamics may strongly attenuate flow making the profile of maximum flow difficult to determine.

The unsteady and steady flow versions of the Chézy equation have been used to generate a mathematical relationship for explaining the loop in the stage-discharge rating curve.

The unsteady discharges can be computed from Eq. 8.11 below, obtained by substituting the energy/friction slope (Eq. 8.8) in the Chézy equation.

$$Q_w = CA\sqrt{R} \sqrt{S_0 - \frac{\partial y}{\partial x} - \frac{v}{g} \frac{\partial v}{\partial x} - \frac{1}{g} \frac{\partial v}{\partial t}} \quad (8.11)$$

where, Q_w is the discharge (m^3/s), C is the Chézy coefficient (in $\text{m}^{1/2}/\text{s}$), A is the cross-sectional area of flow (in m^2), R is the hydraulic radius (in m) and the other variables are as defined before. The steady discharge in a steady, uniform flow can be computed from Eq. 8.12.

$$Q_{w0} = CA\sqrt{RS_0} \quad (8.12)$$

where, Q_{w0} is the discharge when the flow is steady and uniform and the other variables have already been defined.

Dividing Eq. 8.11 by Eq. 8.12 results in Eq. 8.13 used to explain the dynamic stage-discharge relationship at a point for a flood wave progressing downstream in a river reach.

$$Q_w = Q_{w0} \sqrt{1 - \frac{1}{S_0} \left(\frac{\partial y}{\partial x} + \frac{v}{g} \frac{\partial v}{\partial x} + \frac{1}{g} \frac{\partial v}{\partial t} \right)} \quad (8.13)$$

Simulation of the dynamic relationship that exists between stage and discharge when the energy slope is variable (unsteady, non-uniform flow) can be achieved by the loop-rating stage-discharge conversion method (Fread, 1973, 1975). A unique, dynamic stage – discharge relation for a particular location along the channel can be determined with a mathematical model based on the complete one-dimensional Saint-Venant equations of unsteady flow (Chow, 1959; Henderson, 1966; Fread, 1975; Eqs. 8.14 and 8.15).

$$A \frac{\partial v}{\partial x} + v \frac{\partial A}{\partial x} + b \frac{\partial h}{\partial t} = 0 \quad (8.14)$$

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} + g \left(\frac{\partial y}{\partial x} + S_e - S_0 \right) = 0 \quad (8.15)$$

where, x is the distance along the channel, in m ; b is the width of the channel at the water surface, in m ; S_0 is the effective channel bottom slope, in m/m ; h is the water surface elevation above a datum plane and the other variables are as defined earlier.

The Saint-Venant equations are solved together with the Manning equation (Eq. 8.16), which accounts for energy losses due to the resistance of the channel boundary.

$$Q_w = \frac{1}{n} AR^{2/3} S_e^{1/2} \quad (8.16)$$

where, n is the Manning roughness coefficient, in $\text{sec}/\text{m}^{1/3}$; and the other variables are as defined above.

The Saint-Venant equations and the Manning equation (Eqs. 8.14-8.16) are used to compute either stage or discharge when the temporal variation of the other is specified (observed or predicted).

A more detailed hydraulic routing of the dynamic wave can be accomplished with Dynamic Wave Routing Operation (DWOPER) (Fread, 1978). The model is based on the complete one-dimensional Saint-Venant equations, solved by a weighted four-point nonlinear implicit finite difference scheme using a Newton-Raphson iterative technique.

The major drawback to full dynamic routing models such as DWOPER is that they are time-consuming and data-intensive, and the numerical solutions often fail to converge when rapid changes (in time or space) are being modelled. Though, this can be addressed by adjusting the time and distance steps used in the model, memory or computational time limits the number of time and distance steps that may be used. In addition, full dynamic one-dimensional routing models do not describe multi-dimensional situations such as in major confluences where lateral velocities and forces are important. In view of these drawbacks and the less stringent scale of resolution at which the river habitat model operates, a simple method described below, which was suggested by Henderson (1966) and developed by Fread (1975) for simplifying these equations, has been adopted.

Some of the assumptions made by Fread (1975) and Henderson (1966) in simplification of the Saint-Venant equations so that they could be solved, and that have been adopted in this study are:

- (1) Lateral inflow or outflow is negligible

(2) The channel width is essentially constant, i.e.,

$$\frac{\partial b}{\partial x} \approx 0$$

(3) Flows are gradually varied, and

(4) The energy losses from channel friction and turbulence are described by the Manning equation.

Assuming a rectangular geometry for which $A=by$ and using assumption (2) above, Eq. 8.14 may be expressed as:

$$\frac{\partial v}{\partial x} = -\frac{vb}{A} \frac{\partial y}{\partial x} - \frac{b}{A} \frac{\partial h}{\partial t} \quad (8.17)$$

Rearrangement of Eq. 8.15 gives the same expression for variable energy slope as that in Eq. 8.8. Substituting Eq. 8.17 and $v=Q_w/A$ in Eq. 8.8, results in the following expression for variable energy slope S_e :

$$S_e = S_0 + \left(\frac{Q_w^2 b}{gA^3} - 1 \right) \frac{\partial y}{\partial x} + \frac{Q_w b}{gA^2} \frac{\partial h}{\partial t} - \frac{1}{g} \frac{\partial \left(\frac{Q_w}{A} \right)}{\partial t} \quad (8.18)$$

A method based on kinematic wave principle, given as the following expression (Eq. 8.19) obtained from Henderson (1966) and Fread (1975) has been adopted to eliminate the need for spatial resolution in Eq. 8.18.

$$\frac{\partial y}{\partial x} = -\frac{1}{c} \frac{\partial h}{\partial t} - \frac{2S_0}{3r^2} \quad (8.19)$$

in which c is the kinematic wave velocity and r is the ratio of the channel bottom slope (S_0) to the average water surface slope (S_w). The value of r is used in Eq. 8.19 as part of a small correction which accounts for the fact that a typical flood wave is not exactly a kinematic wave (Fread, 1975). Typical values of r have been found to lie in the range 10 to 100 (Fread, 1975).

The use of the kinematic wave principle in the form presented to eliminate the need for spatial resolution in Eq. 8.18 may reduce the width of the stage-discharge loop (Fig. 8.3)

but may not necessarily reduce the flow to steady uniform flow with no loop in the rating curve. This is because the acceleration components are still significantly retained. The acceleration terms are not ignored except that the kinematic wave principle in this form is applied to eliminate the spatial resolution partly in the spatial acceleration term and the pressure term. Similar application of the same method by Fread (1975) never eliminated the loop in the rating curve. It is however important to emphasize the importance of the width of the loop. The width of the loop is an indication of the importance of the inertia and pressure terms (Graf and Qu, 2004).

The kinematic wave velocity may be computed from the relationship below obtained from Fread (1975).

$$c = \lambda v = \lambda \frac{Q_w}{A} \quad (8.20)$$

where, λ is the ratio of the maximum kinematic wave velocity (c) to the water velocity (v). The speed of the main flood wave has been found to approximate that of the kinematic wave (Henderson, 1966). The kinematic wave velocity can also be expressed in terms of the relationship below obtained from Graf and Altinakar (1998).

$$c = v + h \frac{\partial v}{\partial h} \quad (8.21)$$

Considering a wide rectangular channel and substituting Manning's equation (Eq. 8.16) into Eq. 8.21 results in Eq. 8.22.

$$c = \frac{5}{3} v \quad (8.22)$$

Thus on the basis of the Manning formula, λ is equal to 1.67 or 5/3 for flow in a wide rectangular channel. Fread (1993) and Chow (1959) among others have also shown the value of λ for a wide rectangular channel to be 5/3. Using this value of λ and determining r as explained in Fread (1975), results in the following expression:

$$r = \frac{72144(Q_{wp} + Q_{wri})T_{rise}S_o}{(h_{pr} - h_{ri})A_a} \quad (8.23)$$

where Q_{wri} is the discharge at the beginning of typical flood on the rising hydrograph limb (m^3/s); Q_{wp} is the peak discharge for typical flood (m^3/s); h_{ri} is the stage at the

beginning of the typical flood on the rising hydrograph limb (m); h_{pr} is the peak stage for typical flood or end of the rising hydrograph limb (m); A_a is the wetted cross-sectional area associated with the average stage, $(h_{ri}+h_{pr})/2$ (m^2); T_{rise} is the interval of time from the beginning of rise in stage until the occurrence of the peak stage (days); and, S_o is as defined earlier.

After substituting for A_a , Eq. 8.23 simplifies to Eq. 8.24.

$$r = \frac{144288(Q_{wp} + Q_{wri})T_{rise}S_o}{b(h_{pr}^2 - h_{ri}^2)} \quad (8.24)$$

The value of r in the falling limb of the hydrograph is given by Eq. 8.25.

$$r = \frac{144288(Q_{wp} + Q_{wff})T_{fall}S_o}{b(h_{pf}^2 - h_{ff}^2)} \quad (8.25)$$

where, Q_{wff} is the final falling limb discharge (m^3/s); h_{ff} is the final falling limb stage (m); h_{pf} is the peak stage corresponding to the falling limb (m); and T_{fall} is the interval of time from the peak in stage until the final falling stage (days).

The procedure given in Fread (1975) has been followed in generating Eq. 8.26. This involved substituting Eq. 8.20 in Eq. 8.19 to generate the new form of Eq. 8.19. This was then substituted in Eq. 8.18 to generate Eq. 8.26 after some rearrangement in which the partial derivatives were replaced by finite difference expressions.

$$S_e = S_o + \left[\frac{A}{\lambda Q_w} + \left(1 - \frac{1}{\lambda}\right) \frac{bQ_w}{gA^2} \right] \delta h_s + \frac{\left(\frac{Q_w'}{A'} - \frac{Q_w}{A} \right)}{g\Delta t} + \frac{2S_o}{3r^2} \left(1 - \frac{bQ_w^2}{gA^3} \right) \quad (8.26)$$

where Δt is the computational time step, in seconds; Q_w' is the discharge at time $t-\Delta t$, in m^3/s ; A' is the cross-sectional area at time $t-\Delta t$, in m^2 ; δh_s is the change in water surface elevation during the Δt time interval, in m; and, $\delta h_s = (h - h')/\Delta t$, where h' is the stage at time $t-\Delta t$.

Equation 8.26 as noted in Fread (1975) is the expression for the variable energy slope S_e which is caused by varying discharge. All of the terms in the right side of Eq. 8.26 except S_o account for the effect of the dynamic characteristics of the flow (Fread, 1975). The

latter author further notes that for steady flow (unchanging with time) the energy slope is constant and equivalent to the bottom slope, S_o . This can be deduced from Eq. 8.26 in which for steady flow all the terms on the right side of the equation except the first term vanish. This is because $Q_w' = Q_w$, $\delta h_s = 0$, and r is infinitely large as the wave slope vanishes for steady uniform flow (Fread, 1975).

After evaluating the energy slope from Eq. 8.26, the dynamic relationship between the stage and the discharge can be determined from the Manning's equation (Eq. 8.16). For example in a wide rectangular channel, in which the hydraulic radius (R) in Eq. 8.16 is approximately equal to the hydraulic depth (i.e. $R \approx D = A/b$), substituting Eq. 8.26 for variable energy slope in Manning's equation (Eq. 8.16) results in Eq. 8.27.

$$Q_w - \frac{AD^{2/3}}{n} \left\{ S_o + \left[\frac{A}{\lambda Q_w} + \left(1 - \frac{1}{\lambda} \right) \frac{b Q_w}{g A^2} \right] \delta h_s + \frac{Q_w' / A' - Q_w / A}{g \Delta t} + \frac{2 S_o}{3 r^2} \left(1 - \frac{b Q_w^2}{g A^3} \right) \right\}^{1/2} = 0 \quad (8.27)$$

Equation 8.27 forms the basis of a model that can be used to determine either discharge when the rate of change of stage is known (as in stream gauging) or stage when the rate of change of discharge is known (as in stream forecasting) (Fread, 1975; <http://www.nws.noaa.gov/>). Equation 8.27 is nonlinear and can be solved by using Newton Iteration Technique (Isaacson and Keller, 1966; Fread, 1973).

As discussed in Fread (1975), the fact that Eq. 8.27 evaluates the variable energy slope in terms of gravity, pressure and inertia forces makes it more accurate for the computation of stage-discharge relationships, unlike most equations that ignore inertia forces. As reported in Fread (1975) some of the equations that only compute the variable energy slope in terms of gravity and pressure forces include those of Linsley *et al.* (1949) and Corbett (1943). The other strong feature of this equation discussed earlier is its ability to compute either the stage or the discharge via the Newton Iteration Technique. This as reported in Fread (1975) is unlike most equations available in literature that only computes the discharge.

The computational procedure for partitioning of the hydrograph into rising limb and falling limb expressed in terms of equivalent steady discharges each of specific duration will be presented in the ensuing paragraphs. The energy slope constitutes the most important unit stream power parameter that has to be determined before computing the unit stream power that has been used as the basis for hydrograph partitioning. This is because it is the main parameter responsible for the variations in sediment movement and storage on the rising limb as compared to the falling limb. Modelling in terms of these two states as discussed in section 8.1 seeks to differentiate the geomorphic effects of high-energy state (rising limb) from those of low-energy state (falling limb). Modelling in terms of these states is considered adequate for ecosystem/habitat management in which coarse scale indication of the direction of geomorphic change has been found to be sufficient (see sections 3.6 and 3.7). It has also been explained that this is the form in which unsteady flow in natural rivers can be transformed to work in steady flow driven episodic sediment budget model. In other words, it makes it possible to apply the inverted episodic sediment budget model in unsteady flow situations prevalent in bedrock-controlled rivers.

The energy slope on the rising hydrograph limb of the unsteady flow profile during the Δt time interval can be computed with Eq. 8.26. If the computation time interval (Δt) is the duration of the rising limb, Q_w' and h' at $t-\Delta t$ become the discharge and the stage at the beginning of the rising limb and Q_w and h at t become the discharge and stage at the end of the rising limb. Thus Q_w and h as Q_{wp} and h_{pr} respectively at the end of hydrograph rising limb and Q_w' and h' as Q_{wri} and h_{ri} respectively at the beginning of hydrograph rising limb will be used in the computation of S_{er} (energy slope in the rising limb of the hydrograph). The use of these flow conditions and substitution of r as given in Eq. 8.24 in Eq. 8.26 gives Eq. 8.28 for computing the energy slope on the rising limb of the hydrograph.

$$S_{er} = S_o + \left[\frac{A_{pr}}{\lambda Q_{wp}} + \left(1 - \frac{1}{\lambda}\right) \frac{b Q_{wp}}{g A_{pr}^2} \right] \delta h_s + \frac{\left(\frac{Q_{wri}}{A_{ri}} - \frac{Q_{wp}}{A_{pr}} \right)}{g t_{rise}} + \frac{2b^2}{3 \times 144288^2 (Q_{wp} + Q_{wri})^2 S_o} \left(1 - \frac{b Q_{wp}^2}{g A_{pr}^3} \right) \delta h_d^2 \quad (8.28)$$

where A_{pr} is the area associated with the peak discharge on the rising limb of the hydrograph; A_{ri} is the cross-sectional area at the beginning of the rising hydrograph limb; $\delta h_s = (h_{pr} - h_{ri})/t_{rise}$; $\delta h_d^2 = (h_{pr}^2 - h_{ri}^2)/T_{rise}^2$.

Computing the S_{er} (Eq. 8.28) when the discharge hydrograph and the initial stage on the rising limb are known requires prior determination of the unknown stage corresponding to the peak discharge on the rising limb of the hydrograph. Such unknown peak stage can be computed using Eq. 8.29 which has been generated by the use of the flow conditions at the beginning and the end of the rising hydrograph limb and substitution of Eq. 8.24 for r on the rising limb in Eq. 8.27.

$$Q_{wp} - \frac{A_{pr} D_{pr}^{2/3}}{n} \left\{ S_o + \left[\frac{A_{pr}}{\lambda Q_{wp}} + \left(1 - \frac{1}{\lambda}\right) \frac{b Q_{wp}}{g A_{pr}^2} \right] \delta h_s + \frac{\left(\frac{Q_{wri}}{A_{ri}} - \frac{Q_{wp}}{A_{pr}} \right)}{g t_{rise}} + \frac{2b^2}{3 \times 144288^2 (Q_{wp} + Q_{wri})^2 S_o} \left(1 - \frac{b Q_{wp}^2}{g A_{pr}^3} \right) \delta h_d^2 \right\}^{\frac{1}{2}} = 0 \quad (8.29)$$

where D_{pr} is the hydraulic depth corresponding to the peak discharge in the rising hydrograph limb and the rest of the variables are as defined earlier.

Equation 8.29 would also be used to compute the unknown peak discharge (Q_{wp}) if the peak stage on the rising limb and the initial stage and discharge conditions were known. However, in the current application, the discharge hydrograph on the rising limb is known (Fig. 8.1) and with the stage corresponding to zero discharge assumed to be zero, Eq. 8.29 can be solved for h_{pr} . Equation 8.29 can be solved for h_{pr} at time t by Newton Iteration in the form presented in Eq. 8.30.

$$h_{pr}^{\beta+1} = h_{pr}^{\beta} - \frac{f(h_{pr}^{\beta})}{df(h_{pr}^{\beta})/dh_{pr}^{\beta}} \quad (8.30)$$

where superscript β denotes the number of iterations; $f(h_{pr}^{\beta})$ is Eq. 8.29 evaluated with the unknown stage corresponding to the peak discharge in the rising hydrograph limb (h_{pr}), which is also implicitly contained in the terms D_{pr} , A_{pr} , b , n and δh_s , replaced by the approximation h_{pr}^{β} ; $df(h_{pr}^{\beta})/dh_{pr}^{\beta}$ is the derivative of $f(h_{pr}^{\beta})$ with respect to h_{pr}^{β} . This format of the Newton Iteration Equation has been adopted from the method reported in <http://www.nws.noaa.gov/>. Thus, in terms of $f(h_{pr}^{\beta})$, Eq. 8.29 can be expressed as:

$$f(h_{pr}^{\beta}) = Q_w - 1.0 \frac{A_{pr} D_{pr}^{2/3} J_0^{1/2}}{n} \quad (8.31)$$

where,

$$J_0 = J_2 + \left[J_3 A_{pr} + J_4 \frac{b}{A_{pr}^2} \right] (h_{pr}^{\beta} - h_{ri}) + \frac{J_5}{A_{pr}} + \left(J_6 b^2 + J_7 \frac{b^3}{A_{pr}^3} \right) (h_{pr}^{2\beta} - h_{ri}^2)^2 \quad (8.32)$$

in which,

$$J_2 = S_0 + \frac{Q_{wri}}{g A_{ri} t_{rise}} \quad (8.33)$$

$$J_3 = \frac{1}{\lambda Q_{wp} t_{rise}} \quad (8.34)$$

$$J_4 = \left(1 - \frac{1}{\lambda} \right) \frac{Q_{wp}}{g t_{rise}} \quad (8.35)$$

$$J_5 = -\frac{Q_{wp}}{g t_{rise}} \quad (8.36)$$

$$J_6 = \frac{2}{3 \times 144288^2 (Q_{wp} + Q_{wri})^2 S_0 T_{rise}^2} \quad (8.37)$$

$$J_7 = -\frac{2 Q_{wp}^2}{3 \times 144288^2 (Q_{wp} + Q_{wri})^2 S_o g T_{rise}^2} \quad (8.38)$$

If the bottom of the channel is assumed to be the datum then, $h_{pr}=D_{pr}$, implying that,

$$f(h_{pr}^\beta) = Q_w - \frac{b h_{pr}^{5/3} J_0^{1/2}}{n} \quad (8.39)$$

The differentiation of Eq. 8.39 to determine $df(h_{pr}^\beta)/dh_{pr}^\beta$ component of the Newton Iteration Equation (Eq. 8.30) gives Eq. 8.40.

$$\frac{df(h_{pr}^\beta)}{dh_{pr}^\beta} = -1.0 \left[\frac{5}{3} \frac{b(h_{pr}^\beta)^{2/3}}{n} J_0^{1/2} + \frac{1}{2} \frac{b(h_{pr}^\beta)^{5/3}}{n} \frac{J_1}{J_0^{1/2}} \right] \quad (8.40)$$

where,

$$J_1 = \frac{dJ_0}{dh_{pr}^\beta} = J_3 b (2h_{pr}^\beta - h_{ri}) + \frac{J_4}{b} \left[\frac{2h_{ri}}{h_{pr}^{3\beta}} - \frac{1}{h_{pr}^{2\beta}} \right] - \frac{J_5}{b h_{pr}^{2\beta}} + 4J_6 b^2 h_{pr}^\beta (h_{pr}^{2\beta} - h_{ri}^2) + J_7 \left(1 + 2 \left(\frac{h_{ri}}{h_{pr}^\beta} \right)^2 - 3 \left(\frac{h_{ri}}{h_{pr}^\beta} \right)^4 \right) \quad (8.41)$$

In the above equations, t_{rise} and T_{rise} will be assumed to be constant for each discharge; h_{ri} is known from the initial conditions; and g , b , n and S_0 are constants. The area A_{pr} at time t_{rise} is a function of the channel width.

The solution for stage by Newton Iteration should meet the following conveyance criteria:

$$\left| h_{pr}^{\beta+1} - h_{pr}^\beta \right| < \varepsilon_{h_{pr}}$$

where, $\varepsilon_{h_{pr}} = 0.001$ m (<http://www.nws.noaa.gov/>).

Equation 8.39 can be used to determine the stage (h_{pr}) for any given peak discharge on the rising limb of the hydrograph. The same equation (Eq. 8.39) can be used to determine the stage on the falling limb of the hydrograph. However, J_0 on the falling limb of the hydrograph will be different from that on the rising limb of the hydrograph due to the differences in the energy slopes. While the energy slope on the rising limb of the hydrograph is computed from Eq. 8.26 that on the falling limb of the hydrograph will be

computed by Eq. 8.42. Also, h_{pr} in Eq. 8.39 will be replaced by the stage corresponding to peak discharge on the falling limb of the hydrograph (h_{pf}).

The same conceptual principles used to obtain the finite difference form of the energy slope equation on the rising limb apply to the falling limb of the hydrograph. This results in the finite difference form of the energy slope on the falling limb of the hydrograph equation below (Eq. 8.42).

$$S_e = S_0 + \left[\frac{A}{\lambda Q_w} + \left(\frac{1}{\lambda} - 1 \right) \frac{b Q_w}{g A^2} \right] \delta h_s + \frac{Q_w' / A' - Q_w / A}{g \Delta t} + \frac{2 S_0}{3 r^2} \left(1 + \frac{b Q_w^2}{g A^3} \right) \quad (8.42)$$

where Q_w' is the discharge at time t , in m^3/s , and Q_w is the discharge at time $t-\Delta t$; $\delta h_s = (h' - h) / \Delta t$, in which, h' is the stage at time t , in m , and h is the stage at time $t-\Delta t$; A is the cross-sectional area at time $t-\Delta t$, and A' is the cross-sectional area at time t .

Equation 8.42 computes the energy slope on the falling hydrograph limb of the unsteady flow profile during the Δt time interval. If the computation time interval (Δt) is the duration of the falling limb, Q_w and h at $t-\Delta t$ become the discharge and the stage at the beginning of the falling limb and Q_w' and h' at t become the discharge and stage at the end of the falling limb. Thus Q_w and h at $t-\Delta t$ as Q_{wp} and h_{pf} respectively and Q_w' and h' as Q_{wff} and h_{ff} respectively will be used in the computation of S_{ef} (energy slope in the falling limb of the hydrograph). The use of these flow conditions at the beginning and the end of the falling hydrograph limb and substituting Eq. 8.25 for r in Eq. 8.42 on the falling hydrograph limb gives the energy slope as Eq. 8.43.

$$S_{ef} = S_0 + \left[\frac{A_{pf}}{\lambda Q_{wp}} + \left(\frac{1}{\lambda} - 1 \right) \frac{b Q_{wp}}{g A_{pf}^2} \right] \delta h_s + \frac{\left(Q_{wff} / A_{ff} - Q_{wp} / A_{pf} \right)}{g t_{fall}} + \frac{2 b^2}{3 \times 144288^2 (Q_{wp} + Q_{wff})^2} S_0 \left(1 + \frac{b Q_{wp}^2}{g A_{pf}^3} \right) \delta h_d^2 \quad (8.43)$$

where A_{pf} is the area associated with the peak discharge on the falling limb of the hydrograph; A_{ff} is the cross-sectional area at the end of the falling limb; $\delta h_s = (h_{ff} - h_{pf}) / t_{fall}$;

$\delta h_d^2 = (h_{pf}^2 - h_{ff}^2) / T_{fall}^2$; T_{fall} is the duration of the falling limb in days and t_{fall} is the duration of the falling limb in seconds.

The same conceptual principles used to obtain the expression for computing the peak stage on the rising limb have been used to obtain the same for computing the peak stage on the falling limb (Eq. 8.44). The flow conditions used are at the beginning and the end of the falling limb.

$$Q_{wp} - \frac{bh_{pf}^{5/3}}{n} \left\{ S_0 + \left[\frac{A_{pf}}{\lambda Q_{wp}} + \left(\frac{1}{\lambda} - 1 \right) \frac{bQ_{wp}}{gA_{pf}^2} \right] \delta h_s + \frac{\left(\frac{Q_{wff}}{A_{ff}} - \frac{Q_{wp}}{A_{pf}} \right)}{gt_{fall}} + \left[\frac{2b^2}{3 \times 144288^2 (Q_{wp} + Q_{wff})^2 S_o} \left(1 + \frac{bQ_{wp}^2}{gA_{pf}^3} \right) \delta h_d^2 \right] \right\}^{\frac{1}{2}} = 0 \quad (8.44)$$

For the falling limb of the hydrograph, J_0 in Eq. 8.39 in which $h_{pr} = h_{pf}$ is given by Eq. 8.45.

$$J_0 = J_2 + \left[J_3 A_{pf} + J_4 \frac{b}{A_{pf}^2} \right] (h_{ff} - h_{pf}) + \frac{J_5}{A_{pf}} + \left(J_6 b^2 + J_7 \frac{b^3}{A_{pf}^3} \right) (h_{pf}^2 - h_{ff}^2)^2 \quad (8.45)$$

In which,

$$J_2 = S_0 + \frac{Q_{wff}}{gA_{ff}t_{fall}} \quad (8.46)$$

$$J_3 = \frac{1}{\lambda Q_{wp} t_{fall}} \quad (8.47)$$

$$J_4 = \left(\frac{1}{\lambda} - 1 \right) \frac{Q_{wp}}{gt_{fall}} \quad (8.48)$$

$$J_5 = -\frac{Q_{wp}}{gt_{fall}} \quad (8.49)$$

$$J_6 = \frac{2}{3 \times 144288^2 (Q_{wp} + Q_{wff})^2 S_o T_{fall}^2} \quad (8.50)$$

$$J_7 = \frac{2Q_{wp}^2}{3 \times 144288^2 (Q_{wp} + Q_{wff})^2 S_o g T_{fall}^2} \quad (8.51)$$

The derivative of the version of Eq. 8.39 for the falling limb of the hydrograph is given by Eq. 8.52.

$$\frac{df(h_{pf}^\beta)}{dh_{pf}^\beta} = -1.0 \left[\frac{5}{3} \frac{b(h_{pf}^\beta)^{2/3}}{n} J_0^{1/2} + \frac{1}{2} \frac{b(h_{pf}^\beta)^{5/3}}{n} \frac{J_1}{J_0^{1/2}} \right] \quad (8.52)$$

J_1 in Eq. 8.52 is thus given by Eq. 8.53:

$$J_1 = \frac{dJ_0}{dh_{pf}^\beta} = J_3 b(h_{ff} - 2h_{pf}^\beta) + \frac{J_4}{b} \left[\frac{1}{h_{pf}^{2\beta}} - \frac{2h_{ff}}{h_{pf}^{3\beta}} \right] - \frac{J_5}{bh_{pf}^{2\beta}} + 4J_6 b^2 h_{pf}^\beta (h_{pf}^{2\beta} - h_{ff}^2) + J_7 \left(1 + 2 \left(\frac{h_{ff}}{h_{pf}^\beta} \right)^2 - 3 \left(\frac{h_{ff}}{h_{pf}^\beta} \right)^4 \right) \quad (8.53)$$

The Manning's roughness coefficient (n) has been estimated from the values of Arcement and Schneider (1989) which covers a range of bed materials from fine sand, coarse sand, gravel, concrete to boulder beds. The interpolated Manning's roughness coefficients for sand sediment samples with D_{50} of 0.775 mm and 1.15 mm used in this study are 0.02475 $\text{sec}/\text{m}^{1/3}$ and 0.02735 $\text{sec}/\text{m}^{1/3}$ respectively.

The ultimate methods for computing the equivalent steady discharges on the rising and falling limbs of the hydrograph have been developed from Fig. 8.4 and Fig. 8.5 respectively on the basis of unit stream power principles. The diagrams (Fig. 8.4 and Fig. 8.5) are directly useful for the computation of the flow volume on each limb (i.e. the area under the hydrograph limb with unsteady discharges and that under its corresponding equivalent steady discharge). The weight of the fluid under the unsteady rising limb of the hydrograph (triangular limb) from Fig. 8.4 is $(\rho g Q_{wp} t_{rise})/2$. Since the energy slope of the rising limb is S_{er} , the unit stream power over the entire duration of the rising limb

component of the triangular hydrograph is $(\rho g Q_{wp} t_{rise} S_{er})/2b$. The weight of the fluid under the equivalent steady discharge on the rising limb over the entire duration of the limb from Fig. 8.4 is given by $\rho g Q_{wres} t_{rise}$. The unit stream power over the entire duration of this corresponding equivalent steady rising limb with flow assumed to be steady and uniform is given by $(\rho g Q_{wres} t_{rise} S_o)/b$. Equating the two unit stream powers on unsteady and steady idealized rising limbs of the hydrograph results in Eq. 8.54.

$$\frac{\rho g Q_{wp} S_{er} t_{rise}}{2b} = \frac{\rho g Q_{wres} S_o t_{rise}}{b} \quad (8.54)$$

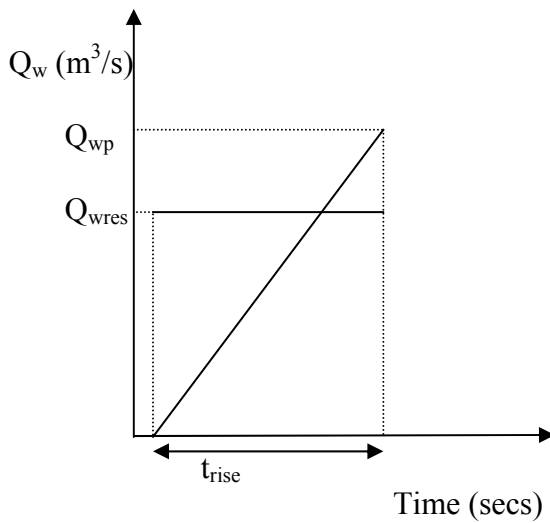


Figure 8.4: Unsteady and equivalent steady idealized rising limbs of the hydrograph

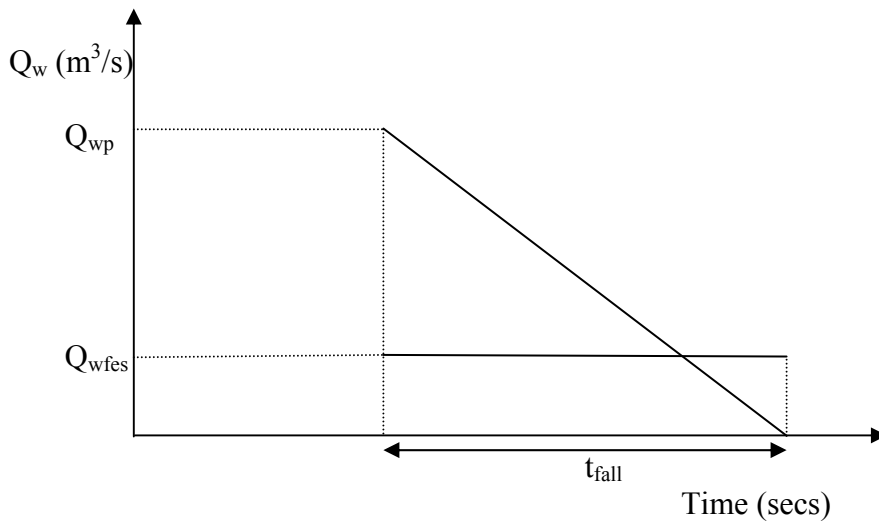


Figure 8.5: Unsteady and equivalent steady idealized falling limbs of the hydrograph

Equation 8.54 simplifies and gives the equivalent steady discharge on the rising limb of the hydrograph as follows:

$$Q_{wres} = \frac{1}{2} Q_{wp} \frac{S_{er}}{S_0} \quad (8.55)$$

The same conceptual principles apply to the falling limb of the hydrograph in Fig. 8.5 and give the equivalent steady discharge on this limb (Q_{wfes}) as:

$$Q_{wfes} = \frac{1}{2} Q_{wp} \frac{S_{ef}}{S_0} \quad (8.56)$$

The two equations (Eq. 8.55 and Eq. 8.56) clearly show that the variation in equivalent steady discharges in each storm of given peak discharge on the rising and the falling limbs of the hydrograph are due to the variations in the energy slopes. Thus energy slope is a critical factor influencing bimodal division into rising and falling limbs of the hydrograph represented by two different steady discharge magnitudes. From the two equations (Eq. 8.55 and Eq. 8.56) it can also be seen that the peak discharge of each discrete hydrograph (Q_{wp}) affects the equivalent steady discharges between either rising limbs or falling limbs of different storms. The bed slope also affects the bimodal division into equivalent steady discharges of given magnitudes on each limb of the hydrograph as it affects the energy slope (see Eq. 8.55 and Eq. 8.56).

The magnitude variations in energy slope on the rising and the falling hydrograph limbs confirm the existence of different sediment transport and storage potentials on the two limbs of the hydrograph. The simplification of the unsteady flow behaviour of each discrete rise-peak-fall hydrograph into two equivalent steady flows on the two limbs of the hydrograph is a desirable feature particularly for determining the bulk sediment storage changes in each limb indicative of the directional change in sediment storage. Computation of the unit stream power in the rising and the falling limbs at the entire duration of each limb based on assumption of linear limb may not provide exact high resolution solutions but is consistent with coarse scale modelling principles for determining directional sediment storage changes discussed in sections 3.6 and 3.7.

Modelling sediment dynamics in terms of the rising and the falling limbs of the hydrograph has the potential to demonstrate high scour potential in the rising limb of each rise-peak-fall discharge hydrograph as compared to the falling limb of the hydrograph. The resulting high and low equivalent steady discharges on the rising and the falling limbs of each rise-peak-fall hydrograph respectively conform to the format that can be directly applied in the inverted episodic sediment budget model to show changes in scour potential. High and low scour potentials in the rising and the falling limbs respectively result because H_{uss} and storage depletion concepts are directly dependent on discharge such that high discharge has high sediment scour potential and low discharge has low sediment scour potential.

This thesis considers the method that has been used in the distribution of unsteady flow to representative steady discharges on the rising and the falling limbs of the rise-peak-fall discharge hydrographs as pragmatic method for transforming complex unsteady flow to simple and easy to apply steady flow. Furthermore, the use of unit stream power principles in the distribution of steady representative discharges on the rising and the falling limbs of the hydrograph ensures realistic estimates of sediment storage changes. This is because unit stream power concept, which is based on flow hydraulics principles, has been conventionally established to drive sediment hydraulics satisfactorily.

Though, the method predicts the total sediment storage change in the entire duration of the rise or the fall and does not capture sediment storage changes at high temporal resolution, it is suitable for routing sediment in bedrock-controlled rivers for ecosystem habitat management. As argued earlier in sections 3.6 and 3.7 the interest in ecosystem habitat management is not exact prediction of quantitative sediment storage changes but directional sediment storage changes. In other words, the interest in river habitat management is to model at a scale and method at which the directional change of alluviation can be captured. Looked at holistically, each rise-peak-fall hydrograph has only two important temporal states of high energy and low energy. At the end of any of these two temporal states (rising limb and falling limb) scour, fill or no change would have occurred in the channel. Thus, a model based on these two temporal states would

provide the river manager with satisfactory answers as to whether there has been scour, fill or no change in alluviation in the river after each temporal state. This information would be useful in decision making regarding the river habitat and the response of different biotic species.

8.4 Outline of the steps required to apply the model

The steps required in applying the model to ideal and field contexts include:

- Idealization of the real world flow hydrograph.
- Computation of the rising limb and the falling limb equivalent steady discharges.
- Classification of the channel into sediment storage units (e.g. channel types and morphology types) of different sediment transport and storage characteristics e.g. pool-rapid channel types, braided channel types, etc.
- Field and/or laboratory measurement of sediment storage changes at equilibrium and with time associated with each discrete or steady discharge in each sediment storage unit of given sediment size range and settling velocities.
- Development of the dimensionless forms of sediment storage changes at equilibrium and with time for each discrete or steady discharge for each sediment storage unit. These correspond to dimensionless H_{uss} and storage depletion curves for the case developed from the laboratory results for pools in this study.
- Determinations of the translation reach characteristics where necessary.
- Application of the model to compute the sediment storage changes with time for increasing time steps during the duration of each idealized hydrograph limb for each steady or equivalent steady discharge in each storage unit with sediment size range of given settling velocities.

The detailed considerations of each of the above steps have either been discussed in this chapter or earlier chapters of this thesis. It is however important to note that a lot more work needs to be done on the field application of the model.

8.5 Graphical illustration of the rising and the falling limbs equivalent steady discharges

Bar graphs have been used to clearly illustrate the dependence of the bimodal distribution of unsteady flow into the rising and the falling limbs equivalent steady discharges on peak discharge magnitude, event duration on each limb of the hydrograph and bed slope. The peak discharge and the bed slope have been shown as important factors that affect the magnitude of the rising and the falling limbs equivalent steady discharges (Eqs. 8.55 and 8.56). The duration on the rising and the falling limbs of the hydrograph indicate how quickly or gradual the flow on each limb of the hydrograph moves. Very gradual flows generally approach steady flows while rapid flows indicate the severity of the unsteady flow condition.

Rising and falling limbs equivalent steady discharges have been computed for a series of four hypothetical idealized triangular discrete discharge hydrographs separated by non-event periods (Fig. 8.6). The first event entered after 1 hour. Each of the four events lasted 30 minutes in the rising limb and 1 hour in the falling limb followed by 1 and a half hours of non-event period. The rising and falling limbs equivalent steady discharges have been computed using the procedure (conceptual principles) and conditions presented in sub-section 8.3.3. Newton iteration has been used to estimate the peak stage corresponding to the peak discharge from either Eq. 8.29 or Eq. 8.44 for the rising and the falling limbs of each of the individual hydrographs respectively. The initial discharge and the corresponding initial stage were each assumed to be zero in each rising limb of the individual rise-peak-fall hydrographs (Fig. 8.6). Similarly, the final discharge and the corresponding final stage were each assumed to be zero in each falling limb of the individual rise-peak-fall hydrographs (Fig. 8.6). The iteration was continued in each case until $|h^{\beta+1} - h^{\beta}| < 0.001 \text{ m}$ (<http://www.nws.noaa.gov/>).

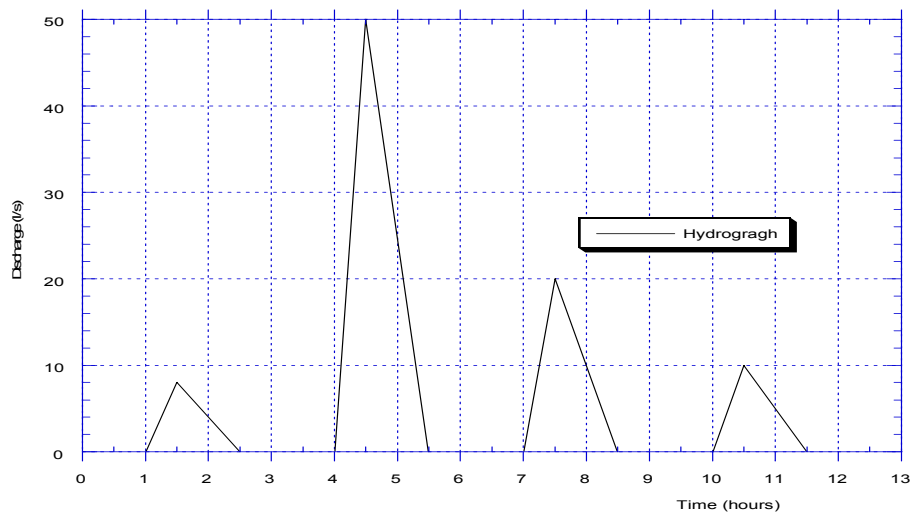


Figure 8.6: Quick rising and falling hypothetical discrete discharge hydrographs separated by non-event periods

The peak stages were used in the computation of the energy slopes from Eq. 8.28 and Eq. 8.43 for the rising and the falling limbs of the hydrograph respectively. The energy slopes were then used to compute the rising and the falling limbs equivalent steady discharges from Eq. 8.55 and Eq. 8.56 respectively.

The energy slopes of the rising and the falling limbs of the single rise-peak-fall hydrographs for sediment samples of $D_{50}=0.775$ mm and $D_{50}=1.15$ mm are presented in Table 8.1. Similarly, the idealized rise and fall discrete hydrographs for flow over the laboratory scale experimental channel when the sediment sizes were of D_{50} of 0.775 mm and 1.15 mm are presented in Fig. 8.7 and Fig. 8.8 respectively. The laboratory channel width of 380 mm and a bed slope of 0.000784 were used in the numerical computation.

Table 8.1: Energy slopes of the quick rising and falling single hydrographs for a bed slope of 0.000784 and sediment samples of $D_{50}=0.775$ mm and $D_{50}=1.15$ mm

Peak Discharge (l/s)	$D_{50}=0.775$ mm		$D_{50}=1.15$ mm	
	S_{er}	S_{ef}	S_{er}	S_{ef}
8	0.000909	0.000714	0.000927	0.000706
10	0.000915	0.000711	0.000933	0.000703
20	0.000932	0.0007	0.000954	0.00069
50	0.000959	0.000682	0.000985	0.000679

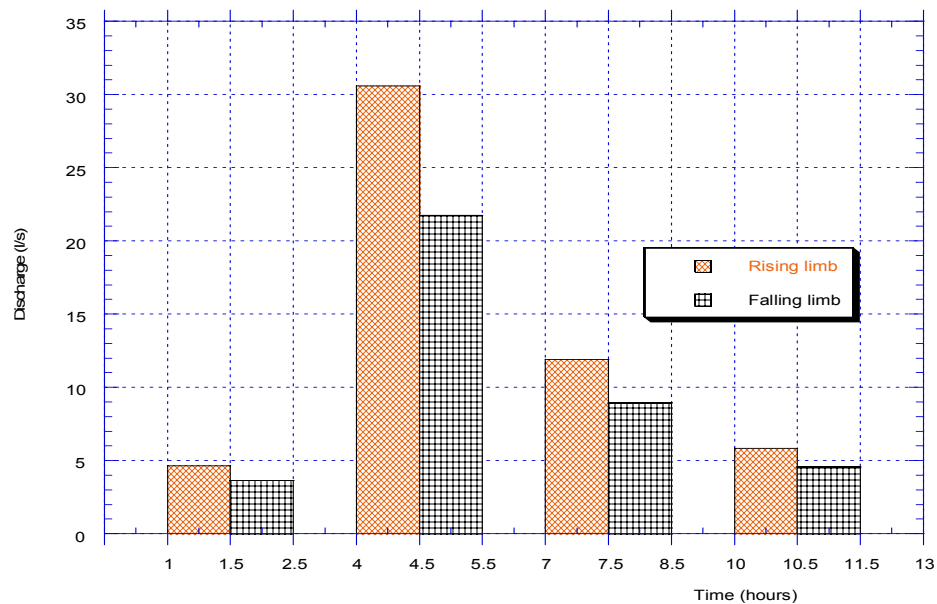


Figure 8.7: Quick rising and falling limbs equivalent steady discharges of hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 0.775 mm and bed slope of 0.000784.

The rising limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=0.775$ mm (Fig. 8.7) and the corresponding rising limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=1.15$ mm (Fig. 8.8) varied in the order of one-tenth of litres/sec. Similarly, the falling limb equivalent steady discharges when the

bed was filled with sediment of $D_{50}=0.775$ mm (Fig. 8.7) and the corresponding falling limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=1.15$ mm (Fig. 8.8) followed the same order of discharge variations. The minor variations in the corresponding equivalent steady discharges whether for the corresponding pairs of rising limbs or falling limbs for different sediment sizes were caused by the differences in the Manning's roughness coefficients (sub-section 8.3.3).

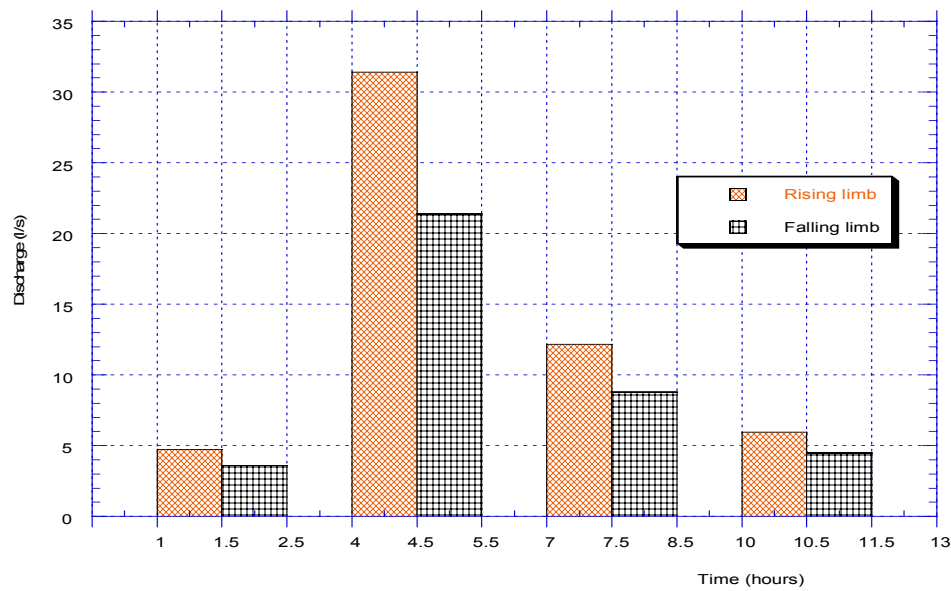


Figure 8.8: Quick rising and falling limbs equivalent steady discharges for hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 1.15 mm and bed slope of 0.000784.

Comparison of Fig. 8.6 with Fig. 8.7 and Fig. 8.8 shows that the bigger and the smaller the peak discharge the bigger and the smaller the equivalent steady discharge on either the corresponding rising or falling limbs of the different discrete hydrographs respectively. Thus the magnitudes of rising and falling limbs equivalent steady discharges for each rise-peak-fall hydrograph depend on the magnitude of the peak discharge as explained in sub-section 8.3.3.

The rising limb equivalent steady discharge is greater than the falling limb equivalent steady discharge for each rise-peak-fall discharge hydrograph (Figs. 8.7 and 8.8). This is because the energy slope on the rising limb is greater than the energy slope on the falling limb (Table 8.1). This confirms the fact that the energy slope is a critical factor influencing the bimodal division of the single rise-peak-fall discharge hydrograph into the rising and the falling limbs equivalent steady discharges as discussed in sub-section 8.3.3.

Quick rising and falling limbs single hydrographs have been compared with gradually rising and falling limbs single hydrographs to determine the effect of event duration on the bimodal distribution of unsteady flow into rising and falling limbs equivalent steady discharges. The single rise-peak-fall hydrographs were of the same peak discharge magnitudes in both the quick and gradual cases (Figs. 8.6 and 8.9 respectively). In the gradual example, the first event entered after 10 hours. Each of the four gradual events lasted 5 hours in the rising limb and 10 hours in the falling limb followed by 15 hours of non-event period (Fig. 8.9).

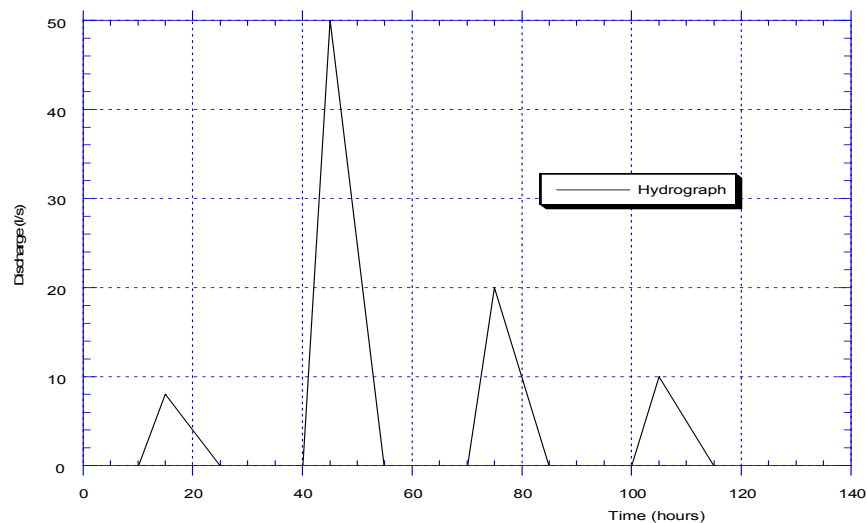


Figure 8.9: Gradually rising and falling hypothetical discrete discharge hydrographs separated by non-event periods

The rising and falling limbs equivalent steady discharges for the gradual example have been computed using the same procedure and conditions used in the computation of the rising and the falling limbs equivalent steady discharges for the quick example. The idealized rise and fall discrete hydrographs for flow over the laboratory experimental channel when the sediment sizes were of D_{50} of 0.775 mm and 1.15 mm have been presented in Fig. 8.10 and Fig. 8.11 respectively for the gradual case. The same laboratory channel width of 380 mm, a bed slope of 0.000784 and similar assumptions of initial discharge and stage in the rising limb being zero and final discharge and stage of the falling limb being zero have been used in the numerical computation for the gradual case as for the quick case.

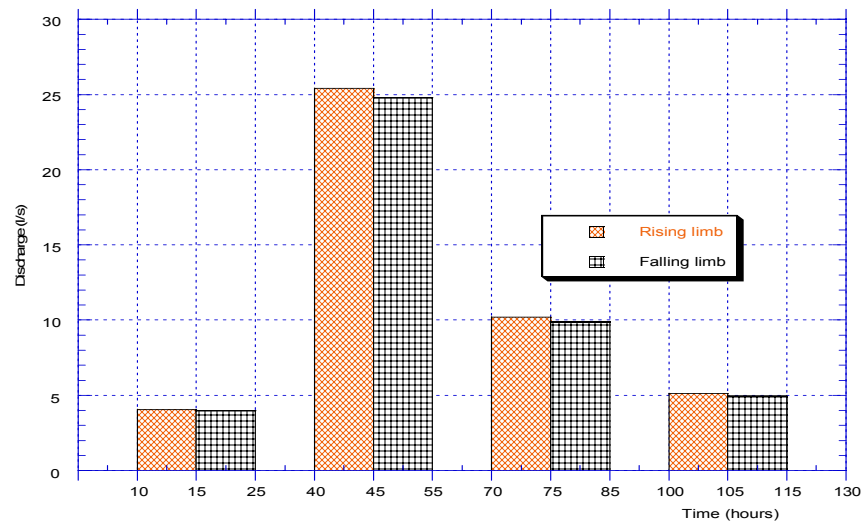


Figure 8.10: Gradually rising and falling limbs equivalent steady discharges for hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 0.775 mm and bed slope of 0.000784

The rising limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=0.775$ mm (Fig. 8.10) and the corresponding rising limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=1.15$ mm (Fig. 8.11) varied in the order of one-hundredth of litres/sec. Similarly, the falling limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=0.775$ mm (Fig. 8.10) and the corresponding

falling limb equivalent steady discharges when the bed was filled with sediment of $D_{50}=1.15$ mm (Fig. 8.11) followed the same order of discharge variations. The minor variations in the corresponding equivalent steady discharges whether for the corresponding pairs of rising limbs or falling limbs for different sediment sizes just like for the quick case were caused by the differences in the Manning's roughness coefficients (sub-section 8.3.3).

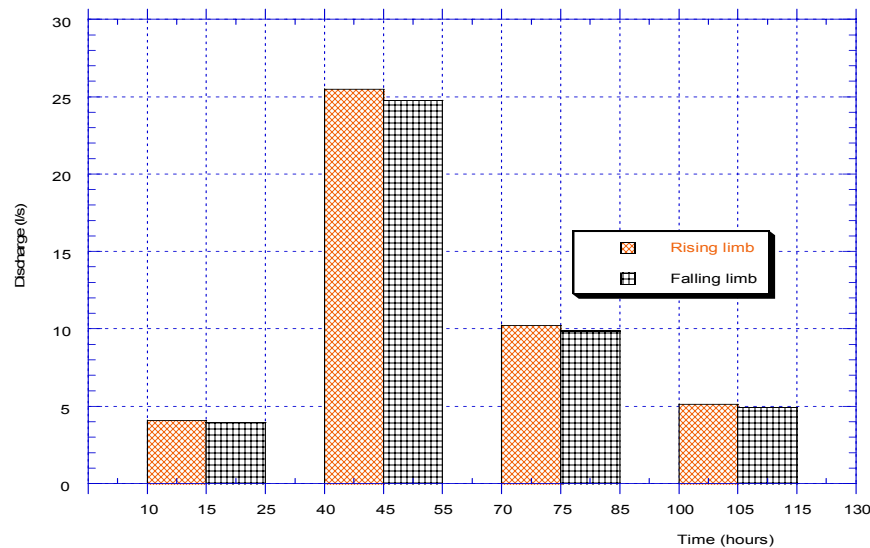


Figure 8.11: Gradually rising and falling limbs equivalent steady discharges for hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 1.15 mm and bed slope of 0.000784

The bimodal distribution of the unsteady flow in single discharge hydrographs into rising and falling limbs equivalent steady discharges shows the distribution as nearly equal in each of the limbs (Figs. 8.10 and 8.11) for gradual flow (Fig. 8.9). This shows that for very gradually varied flow (nearly steady) there is no significant variation on the rising limb and falling limb steady discharges for each single rise-peak-fall hydrograph. This is because there are no significant variations in the energy slopes (Table 8.2). Such a situation may not need the bimodal distribution of discharges on the rising and the falling limbs of the hydrograph as the same equivalent steady discharge can be used to predict sediment storage changes on both the rising and the falling limbs of the hydrograph.

Table 8.2: Energy slopes of the gradually rising and falling single hydrographs for a bed slope of 0.000784 and sediment samples of $D_{50}=0.775$ mm and $D_{50}=1.15$ mm.

	$D_{50}=0.775$ mm		$D_{50}=1.15$ mm	
Peak Discharge (l/s)	S_{er}	S_{ef}	S_{er}	S_{ef}
8	0.000797	0.000777	0.000798	0.000776
10	0.000797	0.000777	0.000799	0.000776
20	0.000799	0.000775	0.000801	0.000774
50	0.000802	0.000774	0.000804	0.000773

Sediment size has been found to show insignificant variation in corresponding pairs of either rising or falling limbs steady discharges (compare Fig. 8.7 and Fig. 8.8; and Fig. 8.10 and Fig. 8.11). Investigation of the effect of bed slope on the rising and the falling limbs equivalent steady discharges using the four hypothetical single hydrographs (Fig. 8.6 and Fig. 8.9) has therefore only been carried out using sediment of median size $D_{50}=0.775$ mm. The numerical computation has been done at the same channel width of 380 mm with the initial discharge and stage of zero in the rising limb and final discharge and stage of zero in the falling limb as used before. The slope has however been increased by a factor of 10 from 0.000784 to 0.00784. The results for quick and gradual cases given in Fig. 8.12 and Fig. 8.13 respectively show the rising limb equivalent steady discharge to be approximately equal to the falling limb equivalent steady discharge for each single discharge hydrograph. This shows that due to the dominating effect of the relatively steep bed slope over the duration of each limb, the flow passes quickly over the channel reach on both limbs of the hydrograph for both the gradual and quick cases. Thus with a relatively steep bed slope, the effect of duration over the slope is negligible. Table 8.3 has been included to show that the rising and falling limbs equivalent steady discharges for each single hydrograph are approximately equal due to insignificant variations of the corresponding energy slopes.

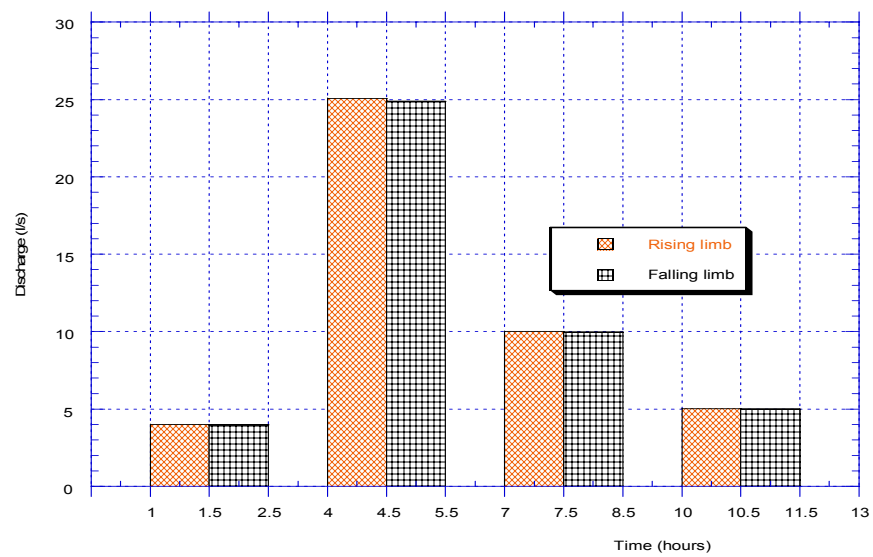


Figure 8.12: Quick rising and falling limbs equivalent steady discharges for hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 0.775 mm and bed slope of 0.00784

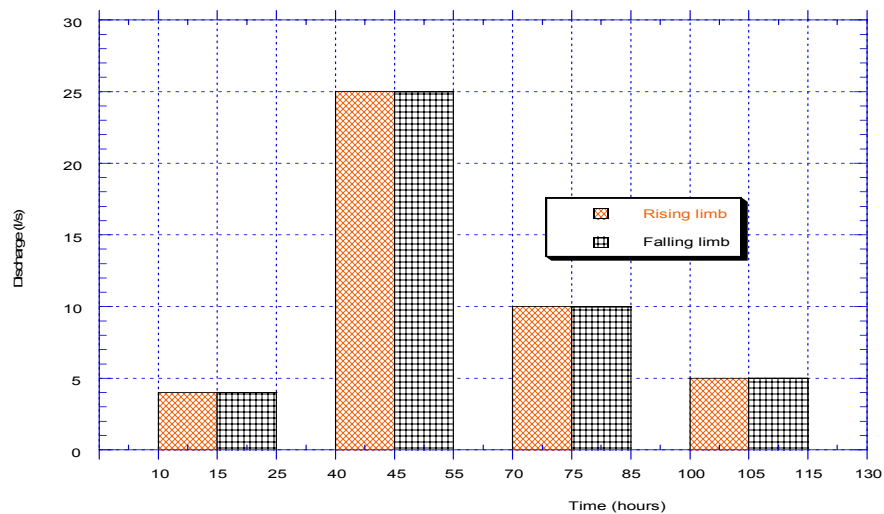


Figure 8.13: Gradually rising and falling limbs equivalent steady discharges for hypothetical discrete discharge hydrographs separated by non-event periods in a laboratory channel filled with sediment of D_{50} of 0.775 mm and bed slope of 0.00784

Table 8.3: Energy slopes of the quick and gradually rising and falling single hydrographs for a bed slope of 0.00784 and sediment sample of $D_{50}=0.775$ mm

Peak Discharge (l/s)	Quick		Gradual	
	S_{er}	S_{ef}	S_{er}	S_{ef}
8	0.007858	0.007816	0.007842	0.007838
10	0.007858	0.007814	0.007842	0.007837
20	0.007858	0.007809	0.007842	0.007837
50	0.007856	0.007800	0.007842	0.007836

Thus in modelling sediment storage changes in steep channel reaches there may be no significant difference between the rising limb equivalent steady discharge and the falling limb equivalent steady discharge. Thus treating the rising limb equivalent steady discharge and the falling limb equivalent steady discharge as approximately equal would be appropriate for such a situation.

It has been established that the binomial distribution of unsteady flow into rising and falling limbs equivalent steady discharges may result in either approximately equal values of equivalent steady discharges on the each of the limbs or higher equivalent steady discharge on the rising limb as compared to the falling limb of the hydrograph. However, these are dependent on the energy slope which is dependent on the discharge magnitude, the duration of each limb of the hydrograph and the channel bed slope.

8.6 The ultimate stable scour depth (H_{uss}) and storage depletion equations

The ultimate stable scour depth (H_{uss}) for the rising limb equivalent steady discharge, the falling limb equivalent steady discharge and the non-event discharge associated with each rise-peak-fall hydrograph were each computed from Eq. 6.13.

The appropriate form of storage depletion equation adopted for routing sediment in pools behind bedrock obstructions with rising and falling limbs of hydrographs is provided in Eq. 8.57.

$$H_{new} = H_{uss} + (H_{prev} - H_{uss}) \exp\left(-k \sqrt{\frac{wt}{y_c}}\right) \quad (8.57)$$

where, H_{prev} is the scour depth attained on routing with the preceding equivalent steady rise discharge or equivalent steady fall discharge or non-event discharge; t is the duration of the current rise discharge, current fall discharge or current non-event discharge; and the rest of the variables are as defined in section 3.9 and sub-sections 4.4.2 and 5.2.4.

The more inclusive form of the storage depletion curve that incorporates the sediment supply and that is therefore more appropriate for routing sediment with rising and falling limbs of discrete hydrographs is:

$$H_{new} = H_{uss} + ((H_{prev} - H_{sup}) - H_{uss}) \exp\left(-k \sqrt{\frac{wt}{y_c}}\right) \quad (8.58)$$

where, H_{sup} is as defined in section 3.9 and the rest of the variables are the same as those defined in Eq. 8.57.

8.7 Sediment routing logic or procedure

The inverted episodic sediment budgeting procedure and code for routing sediment in a series of cells using a steady discharge lasting for some time (Fig. F1 and Code G1 respectively) were modified to account for the rising and the falling limbs of the discharge hydrograph (Fig. F2 and Code G2 respectively). In the development of the latter model, idealized triangular discharge hydrographs were distributed over the rising and the falling limbs into rectangular blocks representing equivalent steady discharge over each limb of the hydrograph (section 8.3) with the use of stream power principles (sub-section 8.3.3). The use of sediment budgeting procedures is, however, the same as that of the inverted episodic sediment budget model for a steady discharge lasting for some time (section 7.4).

The unsteady flow inverted episodic sediment budget model considers the rise duration and the fall duration as single routing time steps. This means that the sediment storage changes over the rising limb of each rise-peak-fall discharge hydrograph is computed in

one routing time step. The same applies to sediment storage changes over the falling limb of each rise-peak-fall discharge hydrograph. This is a coarse scale of resolution, as it does not distinguish the time varying scour rates over the entire sediment routing period for each limb of the hydrograph.

In summary the sediment routing procedures are set out in Fig. F2 and coded in Visual Basic (Code G2) and essentially represent sediment scour modules and sediment storage modules.

8.8 Translation module and treatment of sediment supply

The translation module has been included in the unsteady flow inverted episodic sediment budget model (Fig. F2 and Code G2) to account for the lag in sediment arrival times due to variations in sediment sizes and sediment transport in translation reaches and hence account for the delay in sediment movement from upstream to downstream cells. The translation module concept has been explained in sub-section 7.4.3 and will not be repeated here except for the specific details used in the unsteady flow inverted episodic sediment budget model.

Erosion and deposition are computed at the end of each rise duration or fall duration or non-event duration in each downstream cell with an assumption of full sediment supply of all the sediment scoured from an immediate upstream cell within the same duration. This means that the volume of sediment scoured in any upstream cell of the model is assumed to be moved to the immediate downstream cell in bulk within the rise, fall or non-event duration and becomes available for instantaneous erosion or deposition. The sediment supply includes the sediment from external sources e.g. tributaries and the surrounding catchment. The model assumes that the sediment particles arriving at the downstream edge of the upstream cell before the end of the routing duration are held there. This assumption makes it possible to route sediment in all the cells at any routing duration. The sediment supply and the sediment routing in the downstream cells are therefore assumed instantaneous at the end of each rise, fall or non-event duration.

The appropriate form of storage depletion equation incorporating translation is given by Eq. 8.59.

$$H_{new} = H_{uss} + ((H_{prev} - H_{sup}) - H_{uss}) \exp\left(-k \sqrt{\frac{w}{y_c}} (\sqrt{t} + \sqrt{T_t})\right) \quad (8.59)$$

where, T_t is the translation time; t is the rise duration or fall duration or non-event duration and the rest of the variables are as defined before in section 3.9 and sub-sections 4.4.2 and 5.2.4.

The treatment of sediment supply in the unsteady flow inverted episodic sediment budget model is exactly the same as described in sub-section 7.4.4 for inverted episodic sediment budget model.

8.9 Model results for three pools in series driven by rising and falling limbs equivalent steady discharges of hypothetical single discharge hydrographs

The unsteady flow inverted episodic sediment budget model (Fig. F2 and Code G2) driven by a series of four hypothetical idealized single discharge hydrographs separated by non-event periods (Fig. 8.6) has been applied to route sediment dynamics in three pools in series. Each discrete hydrograph (event) has been treated in terms of the rising limb equivalent steady discharge and the falling limb equivalent steady discharge occurring over the rising and the falling limbs of the hydrograph respectively (Fig. 8.7 and Fig. 8.8).

Quick rising and falling hypothetical discrete discharge hydrographs (Fig. 8.6) have been used in the model because they clearly give binomial distribution of unsteady flows into rising and falling limbs equivalent steady discharges in a laboratory channel filled with sediment of D_{50} of 0.775 mm and 1.15 mm at a bed slope of 0.000784 (Fig. 8.7 and Fig. 8.8). This unlike cases where the rising limb equivalent steady discharges and the corresponding falling limb equivalent steady discharges are approximately equal will make it possible to differentiate the sediment storage changes on the rising and the falling limbs of the hydrograph.

The hypothetical application was aimed at demonstrating the theoretical reasonableness of unsteady flow associated with discrete rise-peak-fall discharge hydrographs, idealized as equivalent steady flow, in routing sediment pragmatically in bedrock-controlled rivers.

In the hypothetical application, the initial scour depths were $H=0$ (pool full) in pool 1 and $H=10$ mm in both pools 2 and 3. Each pool was of length 2.5 m and width 380 mm. The model results with the preceding conditions were produced for two different sediment samples with D_{50} of 0.775 mm and 1.15 mm to show that the application of the unsteady flow inverted episodic sediment budget model works for sediment samples of different size ranges.

The H_{uss} for the idealized rising and falling limbs equivalent steady discharges of each discrete hydrograph in the series are presented in Figs. 8.14 and 8.15 for sediment samples with D_{50} of 0.775 mm and 1.15 mm respectively. This application of the unsteady flow inverted episodic sediment budget model does not include a translation module. The translation module was excluded by making the translation time as input data that feeds into Eq. 8.59 zero.

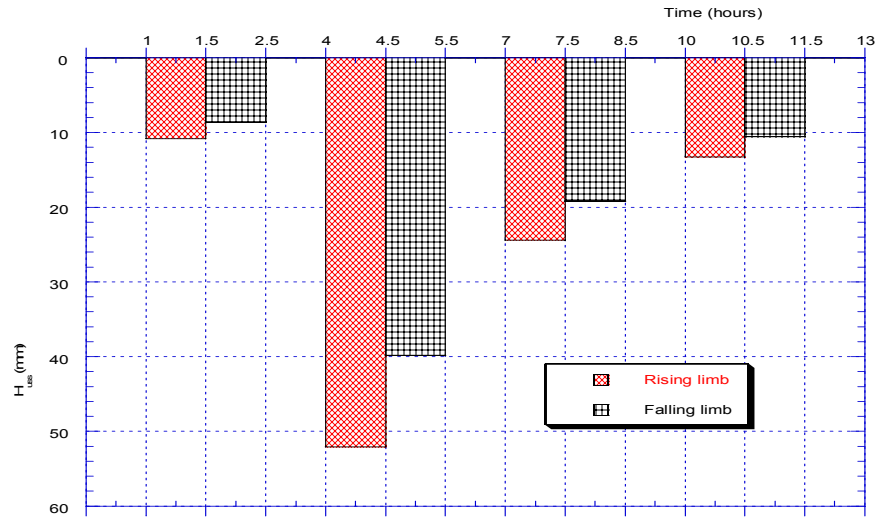


Figure 8.14: The H_{uss} of the rising and the falling limbs equivalent steady discharges of the hypothetical discrete discharge hydrographs over the rise and the fall duration respectively for sediment sample with D_{50} of 0.775 mm

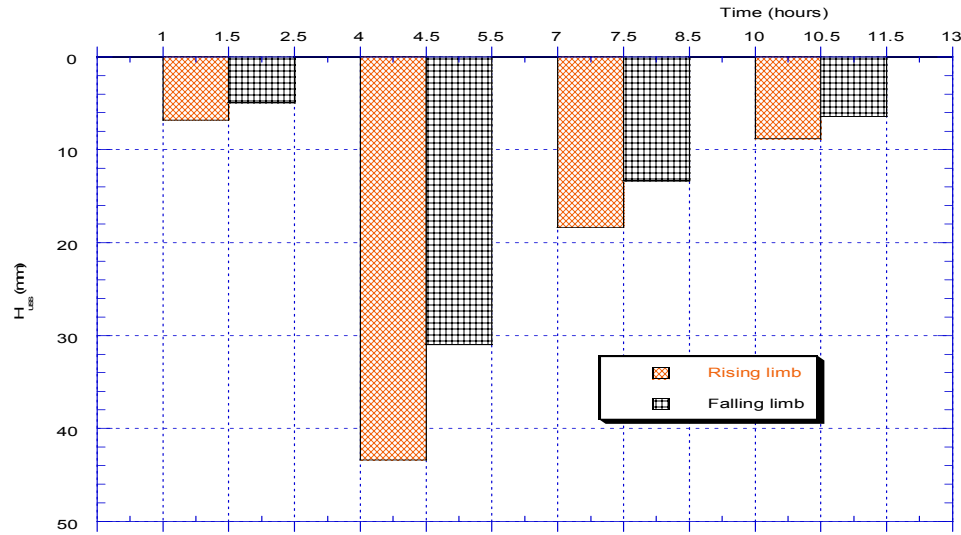


Figure 8.15: The H_{uss} of the rising and the falling limbs equivalent steady discharges of the hypothetical discrete discharge hydrographs over the duration of the rise and the fall for sediment sample with D_{50} of 1.15 mm.

The bar heights representing the H_{uss} for the corresponding rising and falling limbs of the rise-peak-fall hydrographs show that for nearly the same steady discharge (Figs. 8.7 and 8.8), the fine sediment sample with D_{50} of 0.775 mm has clearly discernible bigger H_{uss} (Fig. 8.14) than the coarse sediment sample with D_{50} of 1.15 mm (Fig. 8.15). This can be explained on the basis of the developed method for computing H_{uss} (Eq. 6.13). Based on this method, fine sediment sample with low settling velocity has high H_{uss} compared to coarse sediment sample with high settling velocity for corresponding idealized rising and falling limbs of the hydrograph. For example sediment sample with D_{50} of 0.775 mm and settling velocity of 80.66 mm/sec has a bigger computed H_{uss} than sediment sample with D_{50} of 1.15 mm and settling velocity of 128 mm/sec for the corresponding idealized rising limbs of the discrete hydrographs (Figs. 8.14 and 8.15). The same applies to the corresponding idealized falling limbs of the discrete hydrographs (Figs. 8.14 and 8.15). Further explanation can be given on the basis of Shields' parameter (Eq. 5.2), according to which for the same τ or u_* , lighter and smaller sediment particles are likely to have higher entrainment function compared with heavier and larger sediment particles (see section 5.3).

The unsteady flow inverted episodic sediment budget model computes scour depth in each pool at the end of each rise, fall and non-event period. A vertical straight line starting from the top surface of the pool, where $H=0$, can therefore be used to represent the total scour depth achieved by the end of each routing time for discrete events or in discrete time steps.

Pool 1 showed an increase or no change in scour height from one event to another at the end of each rising limb (Figs. 8.16 and 8.17) with the two sediment samples with D_{50} of 0.775 mm and 1.15 mm. Increase and no change in scour height from one event to another represented sediment scour and no change in sediment storage respectively. The latter condition means that there was no potential to scour the sediment, as the scour hole (H_{prev}) had become deeper than or equal to the H_{uss} of the rising limb for the current rise-fall discrete discharge hydrograph (Figs. 8.16 and 8.17, compare with Figs. 8.14 and 8.15 respectively). For example the rising limb discharges of the first three discharge events

for sediment sample with D_{50} of 0.775 mm each had their H_{uss} (Fig. 8.14) greater than H_{prev} (i.e. initial scour depth or the scour depth after the preceding event) and therefore each scoured sediment towards its H_{uss} (Fig. 8.16). The fourth discharge event with rising limb equivalent steady discharge magnitude of 5.8 litres/sec (Fig. 8.7) and H_{uss} of 13.3 mm (Fig. 8.14) did not scour sediment as the scour hole of 19.7 mm after the third discharge event routing (Fig. 8.16) was already deeper than the H_{uss} . Since there was no sediment supply in pool 1, the scour depth attained in pool 1 after routing with equivalent steady rise discharge of the fourth event remained the same as that attained after routing with the third event (Fig. 8.16).

Similar explanations as those provided in the preceding paragraph are applicable to routing with the rising limbs of the same discharge events when the bed sediment sample has D_{50} of 1.15 mm. In the latter case also the first three events had the potential to scour sediment by the end of their rising limbs, with the fourth event having its rising limb H_{uss} (Fig. 8.15) exceeded by the scour depth already achieved by the first three events (Fig. 8.17).

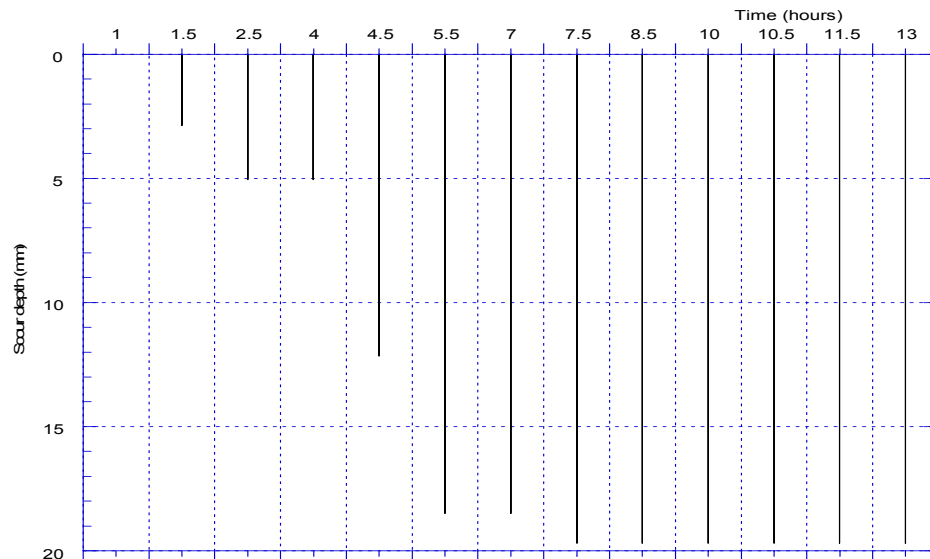


Figure 8.16: Pool 1 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 0.775 mm

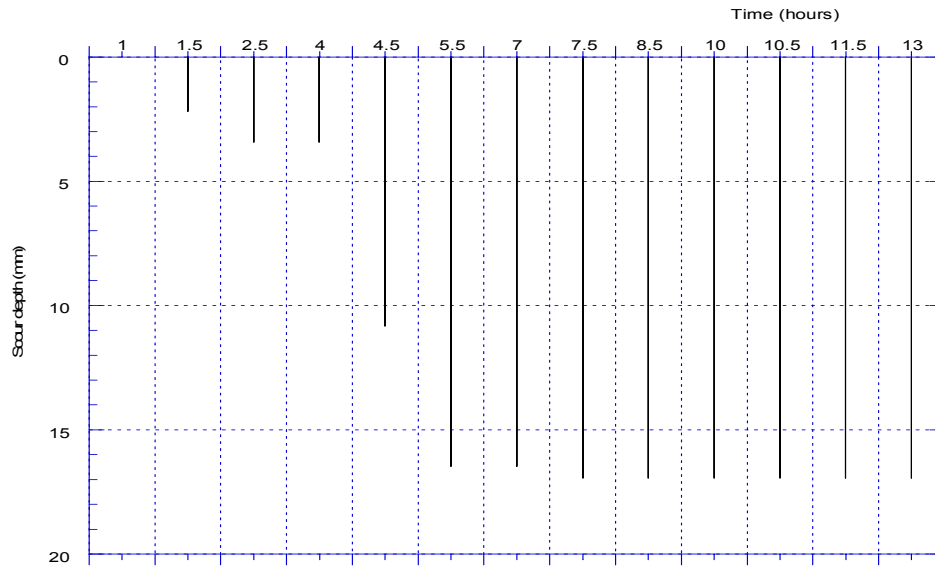


Figure 8.17: Pool 1 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 1.15 mm

The model results for pool 1 (Figs. 8.16 and 8.17) showed that the magnitude of scour depth change over the rising limb of each discrete hydrograph depends on a number of factors. The factors include the event sequence, the magnitude of the scour depth before the current event enters with respect to the H_{uss} of the current event and/or the availability of the scour potential and sediment size. For example considering Fig. 8.17, the rising limb equivalent steady discharge for the first event though smaller than the rising limb equivalent steady discharge for the fourth event (Fig. 8.8) scoured a depth of 2.2 mm of sediment while the rise discharge for the fourth event did not scour sediment. In this case one can argue that the model results for pool 1 contradicted the theoretical expectation based on Eqs. 6.13 and 6.24 that discharge of bigger magnitude scours more sediment than discharge of smaller magnitude. This contradiction in model results can be explained in terms of the event sequence and the magnitude of the scour depth before the current event enters with respect to the H_{uss} of the current event and/or the availability of the scour potential. For example the rising limb equivalent steady discharge of the fourth event, which peaked at 10 litres/sec followed two big events; events two and three that

peaked at 50 litres/sec and 20 litres/sec respectively (Fig. 8.6). By the end of the third event, sediment had been scoured to a deeper depth (16.9 mm) (Fig. 8.17) than the H_{uss} (8.11 mm) of the rising limb of the fourth event (Fig. 8.15). Thus the rising limb equivalent steady discharge of the fourth event had no scour potential. This can be interpreted to mean that if a flood flow is followed by a small discharge event, the latter event may not cause change of geomorphological significance in the river. This is an important illustration that supports the earlier hypotheses that sediment movement in bedrock-controlled rivers is discontinuous and occurs in response to discharge events with the potential to scour and move the sediment.

Comparison of the scour results for pool 1 presented in Figs. 8.16 and 8.17 for a series of four discrete rise-peak-fall discharge hydrographs of the same magnitude and sequence show that the scour magnitude for corresponding rising limbs equivalent steady discharges varies with the sediment size. An event of approximately similar characteristics (i.e. discharge magnitude and duration) applied to fine and coarse sediments clearly scours, more fine sediment than coarse sediment. For example, the rising limb discharge of the first discharge event scoured 2.9 mm of the sediment sample with D_{50} of 0.775 mm (Fig. 8.16) and 2.2 mm of the sediment sample with D_{50} of 1.15 mm (Fig. 8.17). The differences in the scour magnitude follows more from the fact that for nearly the same discharge the H_{uss} for fine sediment is greater than that of the coarse sediment due to differences in their settling velocities (Eq. 6.13). This can be explained further in terms of Shields' method (Eq. 5.2), which states that provided the shear stress or shear velocity remains the same more of the fine sediment will be entrained compared to coarse sediment.

The falling limbs of the first two discrete hydrographs used in the model with the two sediment samples of different sizes (D_{50}) scoured sediment while those of the last two events did not scour sediment in pool 1 (Figs. 8.16 and 8.17). The falling limbs of the last two events had no potential to scour sediment because the scour hole was already deeper than the H_{uss} of the equivalent steady discharge of each falling limb. It is important to note that although the third event had the potential to scour sediment in pool 1 on its

rising limb for both the sediment samples, its falling limb had no potential to scour the sediment. This was because the rising limb had used its high stream power to scour the sediment to a depth deeper than the H_{uss} of its low stream power falling limb. If there was sediment supply then either the potential to scour the sediment might have existed on the falling limb or deposition would have occurred. Thus proper functioning of the model is partly limited to availability of sediment supply, making it a sediment supply limited model. This confirms the importance of H_{uss} and sediment supply that have been identified as some of the key sediment routing parameters in this sediment budget model.

The non-event period is a period of no geomorphic change as reflected in the model results (Figs. 8.16 and 8.17). Thus the non-event periods retained the same scour depth achieved over the falling limb of each discrete discharge hydrograph (Figs. 8.16 and 8.17).

The first event in the application involving the use of sediment sample with D_{50} of 0.775 mm initially had small scour potential in its rising limb ($H_{uss} > H_{prev}$ i.e. 10.8 mm > 10 mm) (Figs. 8.14 and 8.18) to scour sediment in pool 2. The scour potential was increased further by sediment supply from pool 1 as $(H_{prev} - H_{sup})$ was even smaller. However, the high volume of sediment flowing into pool 2 from pool 1 resulted in a net fill (Figs. 8.18). The falling limb of the first event also had $H_{uss} = 8.6$ mm which was only slightly greater than $H_{prev} = 7.8$ mm and showed exactly similar behaviour as the rising limb resulting in net fill in pool 2 (Figs. 8.18). In the application involving the use of sediment sample with D_{50} of 1.15 mm the first event had no scour potential in its rising limb ($H_{uss} < H_{prev}$ i.e. 6.8 mm < 10 mm) (Figs. 8.15 and 8.19) in pool 2 resulting in deposition of sediment from pool 1. The falling limb of the first event also had $H_{uss} = 4.9$ mm which was less than $H_{prev} = 7.4$ mm and showed exactly similar behaviour as the rising limb resulting in deposition of sediment from pool 1 in pool 2 (Figs. 8.19).

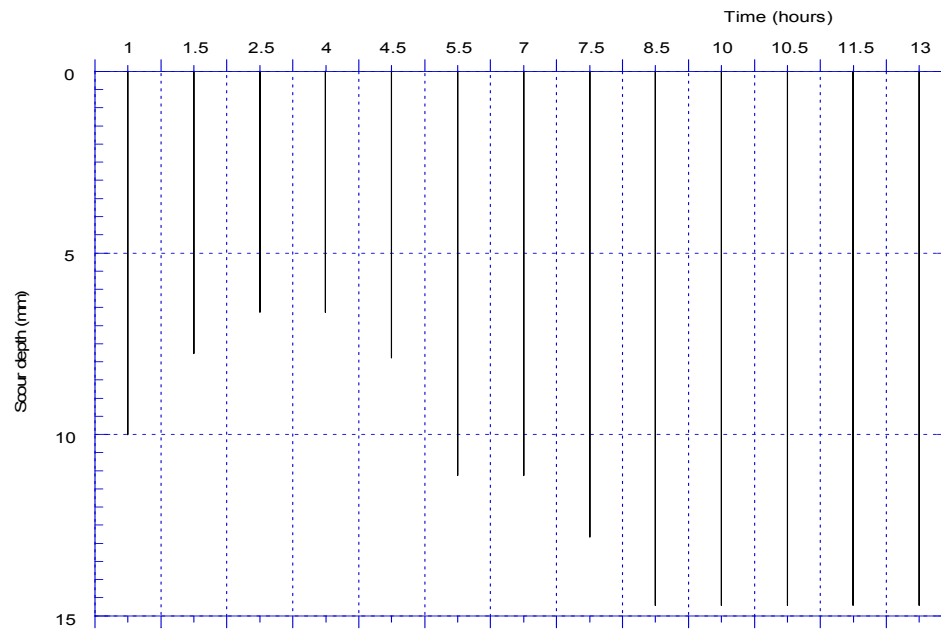


Figure 8.18: Pool 2 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 0.775 mm

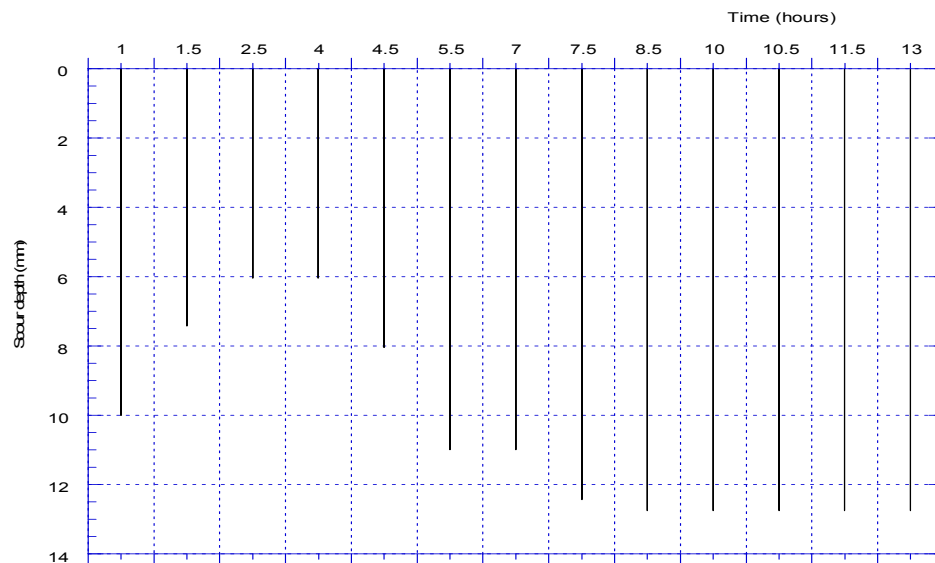


Figure 8.19: Pool 2 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 1.15 mm

The situation was reversed by high scour potential events (events 2 and 3 of peak discharge magnitudes 50 litres/sec and 20 litres/sec respectively) for both the applications with different sediment sizes resulting in scour in pool 2 in both their rising and falling limbs (Figs. 8.18 and 8.19). These two events left the scour hole much deeper than the H_{uss} of the smaller rising and falling limbs equivalent steady discharges of the fourth discrete event and therefore it caused no further storage change in pool 2 (Figs. 8.18 and 8.19) as there was no sediment flowing from pool 1. This was applicable in both the applications with the two different median sediment sizes and in both the rising and the falling limbs.

Comparison of Figs. 8.17 and 8.19 reveals that event 3 had the potential to scour sediment during its falling limb in pool 2 and not pool 1. This can be attributed to sediment supply from upstream cell (pool 1) reducing the scour depth in pool 2 and thus resulting in availability of scour potential (i.e. $(H_{prev} - H_{sup}) < H_{uss}$). The model results thus further confirm sediment supply as a limiting parameter that determines whether there is sediment scour or sediment storage. Thus the model has the potential for routing sediment in situations where sediment supply is limiting as in steep hilly areas and bedrock-controlled rivers (see section 2.4).

The net fill and net erosion in pool 3 with the four discrete events and the effect of their rising and falling limbs can be explained in exactly the same way as done for pool 2 (Figs. 8.20 and 8.21). Net fill and net erosion with different discrete hydrographs and over their rising and falling limbs shows that the model captures continuous interactive geomorphic processes of erosion and storage. The reversal of the net fill in pools 2 and 3 with later events of higher scour potential can also be explained partly by reduced sediment supply from the immediate upstream pools as there was no external replenishment of sediment supply.

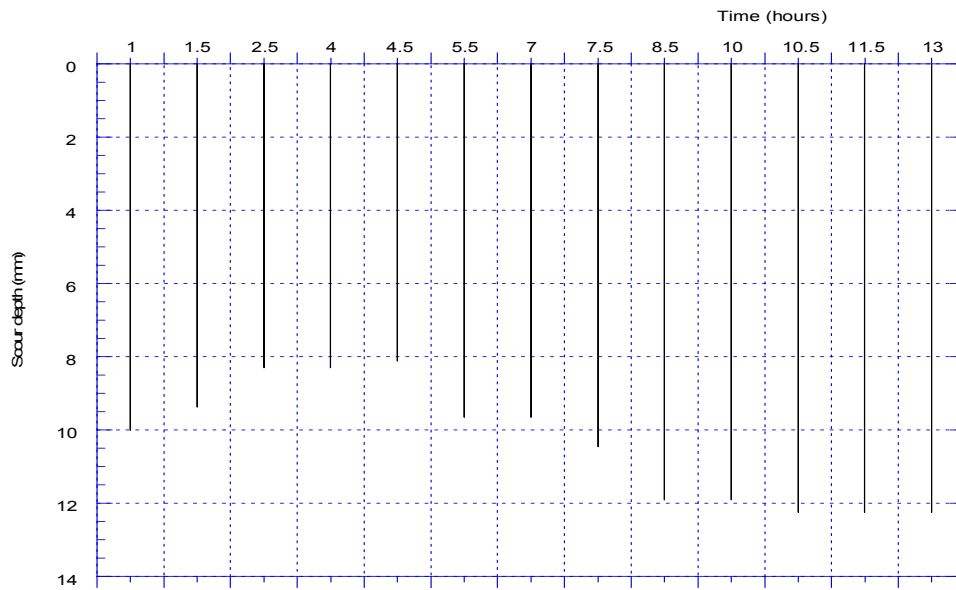


Figure 8.20: Pool 3 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 0.775 mm

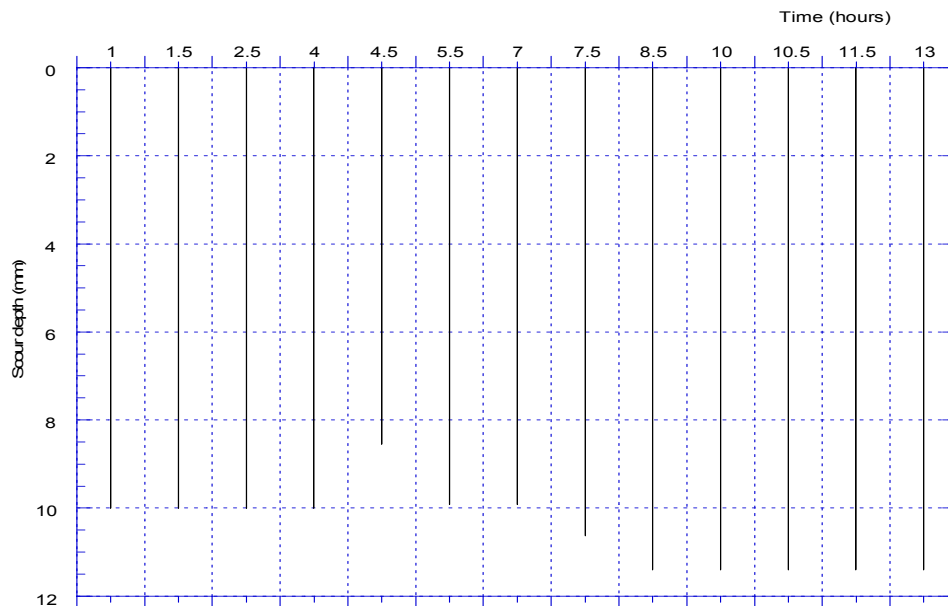


Figure 8.21: Pool 3 scour depth-time relationship modelled with unsteady flow inverted episodic sediment budget model for sediment sample with D_{50} of 1.15 mm

The model results show that pool 1 is a net eroding pool and therefore acts as a sediment reservoir for the downstream pools that show either net erosion or net fill depending on the sediment supply and the scour potential. This is an established behaviour of pools or reservoirs in series showing that the model has the potential to route sediment dynamics in a series of pools. The model also demonstrates clearly in pools 2 and 3 that the sediment supply and the discharge are both important controls on sediment dynamics.

8.10 Application of the model to a natural bedrock-controlled river

Application of the model to a natural bedrock-controlled river such as the Sabie River requires that the reach being modelled be divided into sediment storage units of similar characteristics. For example in the Sabie River the modelling can be done either at the channel type scale or morphologic unit scale depending on the scale of resolution required of the results. Fundamentally modelling at the five principal channel types of van Niekerk *et al.* (1995) that include bedrock anastomosing, mixed anastomosing, pool-rapid, braided and alluvial single thread would be appropriate at coarse scale of resolution desired for sediment dynamics models aimed at habitat management. The same channel type scale had been found appropriate in the Birkhead *et al.* (2000) study in which the length of the Sabie River flowing through Kruger National Park was divided into 40 linked cells of alternating channel types.

Modelling the Sabie River at the channel type scale would require that the dimensionless H_{uss} and storage depletion curves be developed for each of the five channel types. The fact that this study has been able to produce these parameters for bedrock pools and the study by James *et al.* (2002) also generated exponential storage depletion changes towards an equilibrium state for lee bars proves that the concept is versatile and therefore can be applied to route sediment in channels of different morphology types.

To determine H_{uss} and storage depletion curve for each channel type, sediment storage changes associated with each independent storm event that produces a discrete discharge hydrograph will be monitored. The end of each recessive limb occurs when sediment

storage changes associated with each flood event that depletes sediment on both the rising and falling limbs of the hydrograph ceases. The ultimate stable state for recessive limbs of such floods will be assumed to have been achieved at the end of the recessive limb. The scour depth achieved from the beginning of the recessive limb (assumed to coincide with peak discharge) to its end will be assumed to constitute the H_{uss} for the equivalent steady discharge of the recessive limb computed from the unit stream power concepts presented in sub-section 8.3.3. The determination of the energy slope will require that either the stage-discharge relationship (the looped rating curve) is measured or the stage corresponding to the peak discharge computed from the solution of the Saint-Venant equations together with the Manning's equation via the Newton-Raphson iteration using the procedure adopted from Fread (1975) in sub-section 8.3.3. The storage change with time constituting the storage depletion curve will be determined for the recessive limb to represent that of equivalent steady discharge on that limb. The sediment storage changes in the immediate upstream cell (sediment storage unit) to the one for which H_{uss} and storage depletion curve is being developed will also be monitored in the same time steps to allow for the adjustment of the sediment supply in determining the storage depletion curve.

The determination of H_{uss} and storage depletion curves for equivalent steady discharges will be repeated for at least five independent flood events in order to calibrate their dimensionless relationships similar to those developed in chapter 6 for each channel type. The calibrated dimensionless H_{uss} and storage depletion curves for any steady discharge on the rising or falling limb of the hydrograph can then be used to model sediment storage changes in a series of interconnected channel types.

8.11 Summary

The theoretically determined rising and falling limbs equivalent steady discharges of a series of discrete discharge hydrographs separated by non-event periods have been used together with the concepts of H_{uss} and storage depletion curve to model sediment dynamics in a series of pools. The model has been referred to as unsteady flow inverted

episodic sediment budget model. The rising and the falling limbs equivalent steady discharges of the discrete discharge hydrographs have been theoretically determined from the unit stream power principles.

The study identified the energy slope as the most important parameter controlling the bimodal division of each discrete hydrograph of given peak discharge into rising and falling limbs of different equivalent steady discharge magnitudes. The bed slope through its control on the energy slope was also found to influence the bimodal division of each discrete hydrograph of given peak discharge into rising and falling limbs of different equivalent steady discharge magnitudes. It was also established that the peak discharge also affects the bimodal division into rising and falling limbs equivalent steady discharges of specific magnitudes by affecting the magnitudes of these equivalent steady discharges in different storms.

The model results show the most upstream pool as a net scouring pool and therefore acting as a sediment reservoir. The downstream pools undergo both net erosion and net fill depending on the magnitude of sediment supply and scour potential. This behaviour is consistent with what was achieved with steady discharges in the laboratory, modelled with the use of the inverted episodic sediment budget model (Fig. F1 and Code G1) demonstrating that the unsteady flow inverted episodic sediment budget model (Fig. F2 and Code G2) has the potential to route sediment dynamics in a series of pools formed behind bedrock obstructions in bedrock-controlled rivers.

It has been demonstrated that this modelling strategy is appropriate for situations where sediment supply or sediment availability in storage is limiting making it more appropriate for routing sediment in bedrock-controlled rivers and upstream steep areas of rivers in general. It has also been illustrated that a flood with high scour potential may not necessarily scour more sediment than one of low scour potential if the latter flood precedes it. Thus the sequence of occurrence of the discharge event (flood event) has been demonstrated to be important as it will determine availability or non-availability of sediment in storage and the availability or non-availability of scour potential. The

procedure for applying the model to natural bedrock-controlled rivers has also been explained. This shows that the model has practical value for routing sediment in natural bedrock-controlled river environments.

CHAPTER NINE

9.0 CONCLUSION AND RECOMMENDATIONS

9.1 Conclusion

The geomorphological characteristics of bedrock-controlled rivers in general and the Sabie River in particular have been reviewed to understand their influence on flow hydraulics and sediment dynamics in such river systems (sections 2.7 and 2.8). Sediment storage changes associated with discrete discharges have been used to develop sediment graphs for routing sediment in bedrock pool models. The developed sediment graphs have the potential to reasonably model sediment dynamics in the other sediment storage units of bedrock-controlled rivers. The sediment graphs are the dimensionless forms of the ultimate stable scour depth (H_{uss}) and the storage depletion curve. The H_{uss} and the storage depletion curve validate the hypothesis that *individual discharge episodes store or erode sediment along a trajectory (storage depletion curve) towards some definable ultimate stable state*.

The H_{uss} of discrete discharges and the exponential decay constant of the storage depletion curve (k) form the key parameters of the inverted episodic sediment budget model. The H_{uss} for each discrete discharge has been used in the model as a decision parameter or a scour potential parameter for determining the availability or non-availability of scour potential. The H_{uss} determines availability or non-availability of scour potential in relation to the scour depth corresponding to the sediment available plus the sediment supply ($H_{prev} - H_{sup}$). The storage depletion curve has been used in the model to describe the path of sediment storage depletion with time within the duration of each discrete (steady) discharge.

The dimensionless forms of H_{uss} and the storage depletion curves for each discrete discharge have been expressed non-dimensionally in terms of the morphology of the sediment storage unit, the scour depth corresponding to the sediment available and/or

sediment supply and the bulk or grain characteristics of the sediment. This has been based on the experimentally observed dependence of sediment storage changes on these parameters and the Buckingham π theorem. The other important considerations in the development of the non-dimensional forms of H_{uss} and storage depletion curve were the flow condition in bedrock-controlled rivers (assumed critical at the relevant control feature) and the nature of storage depletion (experimentally found to follow an exponential decay path with time). In the dimensionless parameters, the settling velocity and the width of the channel have represented the sediment characteristics and the morphology of the channel respectively. The dimensionless relationships were calibrated from the laboratory measured data on scour depth changes with time and scour depth attained at ultimate stable state integrated over the discrete monitoring locations over the entire longitudinal profile of the laboratory pool model. The data used for the calibration of the storage depletion curve were integrated over all the discrete monitoring locations over the entire longitudinal profile in each monitoring time.

The dimensionless parameters derived to describe the relationship between the flow intensity and the scour depth for each representative sediment size of a given settling velocity are $v_c/w=(\sqrt{(gy_c)})/w$ and $(\sqrt{(gH_{uss})})/w$ respectively. The flow intensity $(\sqrt{(gy_c)})/w$ was regressed in a least squares fit with the dimensionless form of H_{uss} (i.e. $(\sqrt{(gH_{uss})})/w$) as the y-axis and a linear relationship with a gradient of 0.90214 and y-intercept of -1.4766 and correlation coefficient (R^2) of 96% was obtained. The dimensionless form of integrated experimental scour depth changes with time optimized in a least squares regression fit with an exponential decay function gave the exponent of time (ϕ) and the exponential decay parameter (k) as 0.5 and 0.0040207 respectively. The optimization results were achieved at a correlation coefficient (R^2) of 96%. These parameters have been used to model sediment dynamics in a series of connected laboratory-simulated pools (Fig. 4.13) by use of the inverted episodic sediment budget model (Code G1). Experimental verification of the modelled scour depth changes with time using integrated scour depth changes measured over the entire longitudinal profile over each model time for each steady discharge in a simulated laboratory pool demonstrated the suitability of

these parameters in modelling sediment dynamics in bedrock-controlled pools (Figs. 7.13-7.18).

The sediment routing logic of the inverted episodic sediment budget model is such that it provides for both sediment scour and sediment storage. Sediment is scoured when $((H_{\text{prev}} - H_{\text{sup}}) < H_{\text{uss}})$ and sediment is stored when $((H_{\text{prev}} - H_{\text{sup}}) > H_{\text{uss}})$ (Fig. F1). When the scour potential exists $((H_{\text{prev}} - H_{\text{sup}}) < H_{\text{uss}})$, the storage depletion curve is used to route sediment. A translation module has been built into the inverted episodic sediment budget model to account for the delay in sediment movement within the channel due to the differences in sediment particle sizes or densities (Shields', 1936) or to model net fills when there is scour potential. Net fill has been shown from experimental results on a series of pools as an important feature of storage depletion when there is high sediment supply (Figs. 5.15, 5.16, 5.17 and 5.18). This results when the scour depth attained on sediment storage depletion (H_{new}) is less than the scour depth before the sediment supply enters (H_{prev}). When there is no scour potential, $((H_{\text{prev}} - H_{\text{sup}}) > H_{\text{uss}})$, the new scour depth (H_{new}) is either equal to H_{prev} if there is no sediment supply or $(H_{\text{prev}} - H_{\text{sup}})$ if there is sediment supply. The sediment routing logic in the inverted episodic sediment budget model has been demonstrated to work pretty well. This is because it has reproduced sediment storage changes observed in experimental confirmation results in a series of pools within limits of experimental errors (Figs. 7.13-7.18). These include showing both net scour and net fill when there is scour potential and showing sediment storage or no change in sediment storage when there is no sediment supply.

Experimental results with a series of steady discharges of different magnitudes and each lasting for a specific duration in a laboratory pool model confirmed sediment routing for each steady discharge follows its storage depletion curve towards its H_{uss} (Figs. 7.11 and 7.12). This further reconfirms the hypothesis that *individual discharge episodes store or erode sediment along a trajectory (storage depletion curve) towards some definable ultimate stable state*. The initial sediment scour depth before each steady discharge enters does therefore not influence the magnitudes of H_{uss} and storage depletion curve for each steady discharge. The validity of the conceptual sediment routing principles of scour

potential being in existence when $((H_{\text{prev}} - H_{\text{sup}}) < H_{\text{uss}})$ and storage potential being in existence when $((H_{\text{prev}} - H_{\text{sup}}) > H_{\text{uss}})$ was also validated. The latter conceptual routing principle was observed in the experimental results from the pool model when steady discharges that entered after the immediate previous steady discharge had scoured the sediment to a scour hole deeper than the H_{uss} of the current steady discharge resulted in no scour. The scour depth remained the same, as there was no sediment supply. The former conceptual routing principle was validated as the discrete discharges that had their H_{uss} and entered at different initial sediment scour states continued to scour sediment along their individual storage depletion curves towards their H_{uss} . The fact that H_{uss} and storage depletion curves are characteristics of discrete discharges was therefore reconfirmed.

The dependence of H_{uss} and storage depletion curve for each steady discharge on sediment supply has been established experimentally using a laboratory pool model (Fig. 5.6). It has been established that the H_{uss} and the storage depletion curve scour depths at any given time when there is sediment supply for the same discharge are less than when there is no sediment supply. Thus the sediment supply contributes to dynamic sediment storage above the no sediment supply scour depths at any given time (active sediment storage). This is provided the initial scour depths are the same with and without sediment supply. The same experimental results have been used to confirm the working of the inverted episodic sediment budget model when there is sediment supply (Figs. 7.7-7.10). The model and experimental scour depth changes with time confirm the suitability of H_{uss} and storage depletion curve for discrete discharges in modelling sediment dynamics in bedrock-controlled pools with and without sediment supply. The experimental verification results with sediment supply were performed on a contracted flume width of 100 mm which was smaller than the full flume width of 380 mm at which the H_{uss} and the storage depletion curve with no sediment supply used in the model were derived. Thus the working of the model parameters in pools of different sizes has therefore been established. The experimental results also established that once the sediment supply is shut down, storage depletion along a storage depletion curve continues until the H_{uss} of

the given steady discharge. These results also confirm the concepts of H_{uss} and storage depletion curve as characteristics of discrete (steady) discharges.

The flow complexity due to the influence of bedrock outcrops, vegetation resistance and discrete sediment deposits complicate the use of conventional analysis of unsteady flow (Saint- Venant equations) to model sediment dynamics. In this study, the Saint-Venant equations have been solved coarsely in order to determine the hydraulic depths on both the rising and the falling limbs of the hydrograph for any given discrete discharge. This has been used to compute the unit stream power on each limb which together with the assumption of equivalent steady discharge at steady uniform flow has been used coarsely to determine the equivalent steady discharge in each limb that can be used in the inverted episodic sediment budget model. This is because the inverted episodic sediment budget model works with steady discharges.

The linking of sediment dynamics to discharge episodes with the potential to scour sediment that has been established to characterize semi-arid bedrock-controlled river systems justifies the use of discrete discharges in modelling sediment dynamics in such river systems. It has theoretically been shown that the treatment of flow in the sediment dynamics model in terms of rising and falling limbs of the discharge hydrograph discretely captures the variations in energy slopes and hence unit stream power in the two limbs of the hydrograph (subsection 8.3.1). An unsteady flow inverted episodic sediment budget model (Code G2) using idealized rising and falling limbs of the discharge hydrograph has been developed. The model has hypothetically been applied with laboratory scale dimensions to show the working of this form of the inverted episodic sediment budget model adaptable for modelling sediment dynamics in bedrock-controlled river field situations. The application of the unsteady flow inverted episodic sediment budget model in a series of laboratory model pools reproduced similar sediment scour and storage characteristics including net scour and net fill when scour potential is available (Figs. 8.12-8.17) as has been observed with the inverted episodic sediment budget model.

The unsteady flow inverted episodic sediment budget model is a suitable ecosystem habitat management model, which can be used to illustrate the sediment storage changes that would result in response to discrete flow hydrographs. This would influence the vegetative response affected by the state of sedimentation in bedrock-controlled rivers, such as the Sabie River in South Africa.

9.2 Recommendations

The inverted episodic sediment budget model developed for modelling sediment dynamics in bedrock-controlled rivers of the type of Sabie River need further improvement. Particularly the sediment storage change characteristics of discrete discharges (H_{uss} and storage depletion curves) derived for the laboratory bedrock pool, need to be derived for the other sediment storage units that have been identified in the Sabie River. The derivation of these parameters experimentally for all the channel types will improve on the understanding of the sediment transport and storage characteristics of the Sabie River and contribute to the development of an improved sediment dynamics model of the River. The differences in the sediment storage units can be simulated by using different flume bed resistances, for example a channel type of low resistance can be represented by a smoothened bed and a channel type of high resistance can be represented by a roughened bed. The representation of the different channel types in the laboratory scale model should also involve use of typical field slopes for each channel type. Channel resistance and channel slopes affect sediment transport and storage by influencing the energy slope. These are thus very important parameters as the energy slope variations are directly responsible for boundary shear stress or stream power variations.

It may also be appropriate to attempt to derive the inverted episodic sediment budget model parameters of H_{uss} and storage depletion curve for exact physical scale models of the different channel types in the Sabie River. While this will contribute to improved understanding and prediction of sediment storage changes in specific storage sites it may lose the essential requirements of generalized predictive cost effective model aimed at

predicting directional changes for ecosystem management at an appropriate scale of resolution. This is because the exact locations and characteristics of bedrock outcrops, vegetative densities and types and discrete sediment deposits that influence flow hydraulics and sediment dynamics in these systems vary even within a storage unit of a specific type. A detailed physical model of this type is therefore complicated to physically simulate and costly in terms of storage change monitoring and may therefore not be useful for general ecosystem management. However, if the objective is to understand and predict sediment storage change in response to discrete discharge hydrographs in for example a specific channel type in a given river reach, then such a study will be useful.

The other important issue that needs to be explored further or improved on is the criteria for splitting discrete hydrographs into the rising and the falling limbs. Though the rigorous theory of unit stream power has been used in deriving the equivalent steady discharges, the assumptions made to allow Saint-Venant equations to be solved together with the assumptions of steady uniform flow lower the resolution of the simulated sediment storage changes. There is need to perform an in depth analysis on the impact of the assumptions to determine the extent to which they lower the resolution of the simulated sediment storage changes. Validation of the model with the sediment storage changes on the rising and the falling limbs of the hydrograph will help in establishing the reasonableness of the model results.

Though flow depths for different discharge magnitudes control the scour depth changes in the sediment storage units, it may be important to investigate how change in obstruction height may influence the magnitudes of H_{uss} and storage depletion curves for specific discharges. Though, this may not change the dimensionless forms of H_{uss} and storage depletion curve for each channel type, it will indicate the effect of obstruction height on sediment storage changes. This is very important especially if there is need to study how large-scale obstructions such as dam walls or weirs will impact on sediment storage changes in response to discrete discharge hydrographs.

The scour depth responses to specific steady or discrete discharges have been successfully used in this thesis to represent sediment storage changes in the laboratory pool models. However, experimental work involving the monitoring of sediment storage changes in terms of the volume of sediment scoured or stored in the channel bed are still essential. The use of volume in defining storage changes (ultimate stable storage and storage change with time) will resolve the inadequacies of the current model in integrating both the lateral and the longitudinal sediment storage changes. The determination of the ultimate stable storage and storage depletion with time volumetrically will contribute to identification of the precision at which scour depth changes are suitable for modelling sediment storage changes. Such a model would also be much easier to apply at the field scale as there will be no need for linear dimensions of the different sediment storage units of the river. The volumetric model will make it easier to model sediment storage changes in discrete morphologic features such as bars and may also be easily extended to model sediment dynamics in estuaries and deltas.

The method has potential for rule-enhancement to account for the spatial distribution of sediment deposits within a cell, and the dynamics and the influence of the vegetation, neither of which can be accounted for easily by conventional modelling methods.

Finally a need exists to explore the potential of the scour depth model (inverted episodic sediment budget model) in predicting scour depth changes in bridge piers and abutments. This and the other recommendations above will improve on the scope of applicability of the modelling concept developed in this thesis. It was, however, not possible to achieve all these within the time domain and resources available for this thesis.

APPENDIX A: Ultimate stable scour depth dataTable A1: Ultimate stable scour depth for Q_w of 3.5 litres/sec and D_{50} of 0.85 mm (Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{uss} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.20	0.20	0.55
1.50	11.20	1.20	10.65	0.65	0.55
2.00	11.55	1.55	11.25	1.25	0.30
2.50	11.95	1.95	11.70	1.70	0.25
3.00	12.30	2.30	11.85	1.85	0.45
3.50	12.70	2.70	12.15	2.15	0.55
4.00	13.10	3.10	12.65	2.65	0.45
4.50	13.50	3.50	13.00	3.00	0.50
5.00	13.90	3.90	13.10	3.10	0.80
5.50	14.25	4.25	13.45	3.45	0.80
6.00	14.65	4.65	13.75	3.75	0.90
6.10	14.70	4.70	13.80	3.80	0.90
6.20	14.80	4.80	13.90	3.90	0.90
6.30	14.90	4.90	14.00	4.00	0.90
6.38	15.00	5.00	14.70	4.70	0.30
Average					0.56

Table A2: Ultimate stable scour depth for Q_w of 5.0 litres/sec and D_{50} of 0.85 mm (Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{uss} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.70	0.70	0.50
2.00	11.55	1.55	10.95	0.95	0.60
2.50	11.95	1.95	11.20	1.20	0.75
3.00	12.30	2.30	11.55	1.55	0.75
3.50	12.70	2.70	12.00	2.00	0.70
4.00	13.10	3.10	12.20	2.20	0.90
4.50	13.50	3.50	12.45	2.45	1.05
5.00	13.90	3.90	12.75	2.75	1.15
5.50	14.25	4.25	13.05	3.05	1.20
6.00	14.65	4.65	13.40	3.40	1.25
6.10	14.70	4.70	13.45	3.45	1.25
6.20	14.80	4.80	13.55	3.55	1.25
6.30	14.90	4.90	13.70	3.70	1.20
6.38	15.00	5.00	14.60	4.60	0.40
Average					0.83

Table A3: Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 0.85 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth, (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.15	0.15	1.05
2.00	11.55	1.55	10.45	0.45	1.10
2.50	11.95	1.95	10.80	0.80	1.15
3.00	12.30	2.30	11.05	1.05	1.25
3.50	12.70	2.70	11.45	1.45	1.25
4.00	13.10	3.10	11.80	1.80	1.30
4.50	13.50	3.50	11.95	1.95	1.55
5.00	13.90	3.90	12.40	2.40	1.50
5.50	14.25	4.25	12.55	2.55	1.70
6.00	14.65	4.65	12.75	2.75	1.90
6.10	14.70	4.70	12.80	2.80	1.90
6.20	14.80	4.80	12.85	2.85	1.95
6.30	14.90	4.90	13.25	3.25	1.65
6.38	15.00	5.00	14.50	4.50	0.50
Average					1.23

Table A4: Ultimate stable scour depth for Q_w of 8.5 litres/sec and D_{50} of 0.85 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.00	0.00	1.20
2.00	11.55	1.55	10.00	0.00	1.55
2.50	11.95	1.95	10.15	0.15	1.80
3.00	12.30	2.30	10.35	0.35	1.95
3.50	12.70	2.70	10.70	0.70	2.00
4.00	13.10	3.10	11.10	1.10	2.00
4.50	13.50	3.50	11.50	1.50	2.00
5.00	13.90	3.90	12.00	2.00	1.90
5.50	14.25	4.25	12.20	2.20	2.05
6.00	14.65	4.65	12.60	2.60	2.05
6.10	14.70	4.70	12.65	2.65	2.05
6.20	14.80	4.80	12.70	2.70	2.10
6.30	14.90	4.90	12.95	2.95	1.95
6.38	15.00	5.00	14.20	4.20	0.80
Average					1.56

Table A5: Ultimate stable scour depth for Q_w of 10.0 litres/sec and D_{50} of 0.85 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.00	0.00	1.20
2.00	11.55	1.55	10.00	0.00	1.55
2.50	11.95	1.95	10.00	0.00	1.95
3.00	12.30	2.30	10.00	0.00	2.30
3.50	12.70	2.70	10.15	0.15	2.55
4.00	13.10	3.10	10.50	0.50	2.60
4.50	13.50	3.50	10.80	0.80	2.70
5.00	13.90	3.90	11.10	1.10	2.80
5.50	14.25	4.25	11.60	1.60	2.65
6.00	14.65	4.65	11.95	1.95	2.70
6.10	14.70	4.70	12.10	2.10	2.60
6.20	14.80	4.80	12.25	2.25	2.55
6.30	14.90	4.90	12.95	2.95	1.95
6.38	15.00	5.00	13.90	3.90	1.10
Average					1.90

Table A6: Ultimate stable scour depth for Q_w of 3.5 litres/sec and D_{50} of 1.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.20	0.20	0.20
1.00	10.75	0.75	10.60	0.60	0.15
1.50	11.20	1.20	11.15	1.15	0.05
2.00	11.55	1.55	11.40	1.40	0.15
2.50	11.95	1.95	11.75	1.75	0.20
3.00	12.30	2.30	12.20	2.20	0.10
3.50	12.70	2.70	12.65	2.65	0.05
4.00	13.10	3.10	13.05	3.05	0.05
4.50	13.50	3.50	13.25	3.25	0.25
5.00	13.90	3.90	13.55	3.55	0.35
5.50	14.25	4.25	13.60	3.60	0.65
6.00	14.65	4.65	13.70	3.70	0.95
6.10	14.70	4.70	13.80	3.80	0.90
6.20	14.80	4.80	13.95	3.95	0.85
6.30	14.90	4.90	14.05	4.05	0.85
6.38	15.00	5.00	14.65	4.65	0.35
Average					0.36

Table A7: Ultimate stable scour depth for Q_w of 5.0 litres/sec and D_{50} of 1.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.15	0.15	0.25
1.00	10.75	0.75	10.30	0.30	0.45
1.50	11.20	1.20	10.75	0.75	0.45
2.00	11.55	1.55	11.05	1.05	0.50
2.50	11.95	1.95	11.45	1.45	0.50
3.00	12.30	2.30	11.85	1.85	0.45
3.50	12.70	2.70	12.05	2.05	0.65
4.00	13.10	3.10	12.40	2.40	0.70
4.50	13.50	3.50	12.60	2.60	0.90
5.00	13.90	3.90	12.95	2.95	0.95
5.50	14.25	4.25	13.20	3.20	1.05
6.00	14.65	4.65	13.45	3.45	1.20
6.10	14.70	4.70	13.50	3.50	1.20
6.20	14.80	4.80	13.60	3.60	1.20
6.30	14.90	4.90	13.75	3.75	1.15
6.38	15.00	5.00	14.60	4.60	0.40
Average					0.71

Table A8: Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 1.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.05	0.05	0.70
1.50	11.20	1.20	10.25	0.25	0.95
2.00	11.55	1.55	10.40	0.40	1.15
2.50	11.95	1.95	10.70	0.70	1.25
3.00	12.30	2.30	11.10	1.10	1.20
3.50	12.70	2.70	11.25	1.25	1.45
4.00	13.10	3.10	11.50	1.50	1.60
4.50	13.50	3.50	11.85	1.85	1.65
5.00	13.90	3.90	12.15	2.15	1.75
5.50	14.25	4.25	12.60	2.60	1.65
6.00	14.65	4.65	12.75	2.75	1.90
6.10	14.70	4.70	12.80	2.80	1.90
6.20	14.80	4.80	12.90	2.90	1.90
6.30	14.90	4.90	13.20	3.20	1.70
6.38	15.00	5.00	14.50	4.50	0.50
Average					1.27

Table A9: Ultimate stable scour depth for Q_w of 8.5 litres/sec and D_{50} of 1.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.10	0.10	1.10
2.00	11.55	1.55	10.35	0.35	1.20
2.50	11.95	1.95	10.65	0.65	1.30
3.00	12.30	2.30	10.85	0.85	1.45
3.50	12.70	2.70	11.15	1.15	1.55
4.00	13.10	3.10	11.45	1.45	1.65
4.50	13.50	3.50	11.70	1.70	1.80
5.00	13.90	3.90	12.05	2.05	1.85
5.50	14.25	4.25	12.55	2.55	1.70
6.00	14.65	4.65	12.65	2.65	2.00
6.10	14.70	4.70	12.70	2.70	2.00
6.20	14.80	4.80	12.85	2.85	1.95
6.30	14.90	4.90	13.10	3.10	1.80
6.38	15.00	5.00	14.35	4.35	0.65
Average					1.36

Table A10: Ultimate stable scour depth for Q_w of 10.0 litres/sec and D_{50} of 1.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.00	0.00	0.40
1.00	10.75	0.75	10.00	0.00	0.75
1.50	11.20	1.20	10.00	0.00	1.20
2.00	11.55	1.55	10.00	0.00	1.55
2.50	11.95	1.95	10.10	0.10	1.85
3.00	12.30	2.30	10.25	0.25	2.05
3.50	12.70	2.70	10.45	0.45	2.25
4.00	13.10	3.10	10.75	0.75	2.35
4.50	13.50	3.50	11.00	1.00	2.50
5.00	13.90	3.90	11.35	1.35	2.55
5.50	14.25	4.25	11.85	1.85	2.40
6.00	14.65	4.65	12.10	2.10	2.55
6.10	14.70	4.70	12.35	2.35	2.35
6.20	14.80	4.80	12.60	2.60	2.20
6.30	14.90	4.90	13.00	3.00	1.90
6.38	15.00	5.00	14.05	4.05	0.95
Average					1.75

Table A11: Ultimate stable scour depth for Q_w of 3.5 litres/sec and D_{50} of 3.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.40	0.40	0.00
1.00	10.75	0.75	10.75	0.75	0.00
1.50	11.20	1.20	11.20	1.20	0.00
2.00	11.55	1.55	11.55	1.55	0.00
2.50	11.95	1.95	11.95	1.95	0.00
3.00	12.30	2.30	12.30	2.30	0.00
3.50	12.70	2.70	12.70	2.70	0.00
4.00	13.10	3.10	13.10	3.10	0.00
4.50	13.50	3.50	13.50	3.50	0.00
5.00	13.90	3.90	13.90	3.90	0.00
5.50	14.25	4.25	14.25	4.25	0.00
6.00	14.65	4.65	14.65	4.65	0.00
6.10	14.70	4.70	14.70	4.70	0.00
6.20	14.80	4.80	14.80	4.80	0.00
6.30	14.90	4.90	14.90	4.90	0.00
6.38	15.00	5.00	15.00	5.00	0.00
Average					0.00

Table A12: Ultimate stable scour depth for Q_w of 5.0 litres/sec and D_{50} of 3.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.40	0.40	0.00
1.00	10.75	0.75	10.75	0.75	0.00
1.50	11.20	1.20	11.20	1.20	0.00
2.00	11.55	1.55	11.55	1.55	0.00
2.50	11.95	1.95	11.95	1.95	0.00
3.00	12.30	2.30	12.30	2.30	0.00
3.50	12.70	2.70	12.70	2.70	0.00
4.00	13.10	3.10	13.10	3.10	0.00
4.50	13.50	3.50	13.50	3.50	0.00
5.00	13.90	3.90	13.90	3.90	0.00
5.50	14.25	4.25	14.25	4.25	0.00
6.00	14.65	4.65	14.65	4.65	0.00
6.10	14.70	4.70	14.70	4.70	0.00
6.20	14.80	4.80	14.75	4.75	0.05
6.30	14.90	4.90	14.80	4.80	0.10
6.38	15.00	5.00	14.90	4.90	0.10
Average					0.01

Table A13: Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 3.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{uss} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.40	0.40	0.00
1.00	10.75	0.75	10.75	0.75	0.00
1.50	11.20	1.20	11.20	1.20	0.00
2.00	11.55	1.55	11.55	1.55	0.00
2.50	11.95	1.95	11.95	1.95	0.00
3.00	12.30	2.30	12.30	2.30	0.00
3.50	12.70	2.70	12.70	2.70	0.00
4.00	13.10	3.10	13.10	3.10	0.00
4.50	13.50	3.50	13.50	3.50	0.00
5.00	13.90	3.90	13.65	3.65	0.25
5.50	14.25	4.25	13.70	3.70	0.55
6.00	14.65	4.65	13.80	3.80	0.85
6.10	14.70	4.70	13.85	3.85	0.85
6.20	14.80	4.80	13.90	3.90	0.90
6.30	14.90	4.90	14.20	4.20	0.70
6.38	15.00	5.00	14.40	4.40	0.60
Average					0.28

Table A14: Ultimate stable scour depth for Q_w of 8.5 litres/sec and D_{50} of 3.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{uss} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.40	0.40	0.00
1.00	10.75	0.75	10.75	0.75	0.00
1.50	11.20	1.20	11.20	1.20	0.00
2.00	11.55	1.55	11.55	1.55	0.00
2.50	11.95	1.95	11.95	1.95	0.00
3.00	12.30	2.30	12.30	2.30	0.00
3.50	12.70	2.70	12.70	2.70	0.00
4.00	13.10	3.10	13.10	3.10	0.00
4.50	13.50	3.50	13.35	3.35	0.15
5.00	13.90	3.90	13.40	3.40	0.50
5.50	14.25	4.25	13.50	3.50	0.75
6.00	14.65	4.65	13.55	3.55	1.10
6.10	14.70	4.70	13.60	3.60	1.10
6.20	14.80	4.80	13.75	3.75	1.05
6.30	14.90	4.90	14.00	4.00	0.90
6.38	15.00	5.00	14.30	4.30	0.70
Average					0.37

Table A15: Ultimate stable scour depth for Q_w of 10.0 litres/sec and D_{50} of 3.05 mm
(Source of data: Harnett(1998))

Distance from upstream, x (m)	Initial gauge height of sediment (cm)	Initial sediment depth (cm)	Ultimate stable state gauge height of sediment (cm)	Ultimate stable state sediment depth (cm)	Depth of sediment removed, h_{USS} (cm)
0.00	10.00	0.00	10.00	0.00	0.00
0.50	10.40	0.40	10.40	0.40	0.00
1.00	10.75	0.75	10.75	0.75	0.00
1.50	11.20	1.20	11.20	1.20	0.00
2.00	11.55	1.55	11.55	1.55	0.00
2.50	11.95	1.95	11.95	1.95	0.00
3.00	12.30	2.30	12.25	2.25	0.05
3.50	12.70	2.70	12.70	2.70	0.00
4.00	13.10	3.10	13.05	3.05	0.05
4.50	13.50	3.50	13.25	3.25	0.25
5.00	13.90	3.90	13.30	3.30	0.60
5.50	14.25	4.25	13.40	3.40	0.85
6.00	14.65	4.65	13.40	3.40	1.25
6.10	14.70	4.70	13.45	3.45	1.25
6.20	14.80	4.80	13.50	3.50	1.30
6.30	14.90	4.90	13.60	3.60	1.30
6.38	15.00	5.00	14.00	4.00	1.00
Average					0.46

Table A16: Ultimate stable scour depth for Q_w of 6.9 litres/sec and D_{50} of 1.15 mm

Time (hours)	0.0			116.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	11.5	8.5	-0.2
1.000	12.8	2.4	10.4	12.3	9.9	0.5
1.500	17.2	2.5	14.7	11.7	9.2	5.5
2.000	23.2	2.5	20.7	14.7	12.2	8.5
2.500	25.5	0.9	24.6	16.5	15.6	9.0
3.000	32.3	2.0	30.3	17.2	15.2	15.1
3.500	36.2	2.5	33.7	20.0	17.5	16.2
4.000	39.3	2.0	37.3	21.7	19.7	17.6
4.500	43.7	2.0	41.7	25.0	23.0	18.7
5.000	44.4	1.8	42.6	27.7	25.9	16.7
5.500	46.4	2.0	44.4	30.0	28.0	16.4
6.000	51.2	3.4	47.8	33.5	30.1	17.7
6.095	52.3	3.4	48.9	34.0	30.6	18.3
6.190	54.5	3.5	51.0	35.0	31.5	19.5
6.285	56.0	3.3	52.7	35.8	32.5	20.2
6.380	56.9	3.2	53.7	41.3	38.1	15.6
Average						12.7

Table A17: Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 1.15 mm

Time (hours)	0.0			121.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	3.0	0.0	7.4
1.000	16.2	2.4	13.8	8.8	6.4	7.4
1.500	18.7	2.5	16.2	10.9	8.4	7.8
2.000	27.4	2.5	24.9	11.5	9.0	15.9
2.500	29.7	0.9	28.8	13.7	12.8	16.0
3.000	30.0	2.0	28.0	16.4	14.4	13.6
3.500	35.5	2.5	33.0	17.6	15.1	17.9
4.000	41.9	2.0	39.9	20.0	18.0	21.9
4.500	45.3	2.0	43.3	22.9	20.9	22.4
5.000	50.0	1.8	48.2	25.2	23.4	24.8
5.500	55.2	2.0	53.2	28.0	26.0	27.2
6.000	56.4	3.4	53.0	32.2	28.8	24.2
6.095	56.4	3.4	53.0	32.4	29.0	24.0
6.190	55.9	3.5	52.4	33.8	30.3	22.1
6.285	56.0	3.3	52.7	35.5	32.2	20.5
6.380	55.5	3.2	52.3	41.5	38.3	14.0
			35.3		Average	16.9

Table A18: Ultimate stable scour depth for Q_w of 8.4 litres/sec and D_{50} of 1.15 mm

Time (hours)	0.0			96.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	2.5	0.0	13.9
2.000	20.5	2.5	18.0	3.4	0.9	17.1
2.500	22.6	0.9	21.7	10.7	9.8	11.9
3.000	31.9	2.0	29.9	12.3	10.3	19.6
3.500	36.6	2.5	34.1	15.0	12.5	21.6
4.000	39.0	2.0	37.0	16.5	14.5	22.5
4.500	43.8	2.0	41.8	18.5	16.5	25.3
5.000	51.0	1.8	49.2	21.6	19.8	29.4
5.500	52.5	2.0	50.5	24.0	22.0	28.5
6.000	57.3	3.4	53.9	27.7	24.3	29.6
6.095	58.2	3.4	54.8	28.2	24.8	30.0
6.190	58.3	3.5	54.8	29.3	25.8	29.0
6.285	58.4	3.3	55.1	31.5	28.2	26.9
6.380	58.4	3.2	55.2	37.3	34.1	21.1
					Average	20.4

Table A19: Ultimate stable scour depth for Q_w of 6.9 litres/sec and D_{50} of 0.775 mm

Time (hours)	0.0			29.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5
1.000	157.5	146.4	11.1	150.0	3.6	7.5
1.500	161.9	146.4	15.5	148.7	2.3	13.2
2.000	166.4	146.0	20.4	154.6	8.6	11.8
2.500	167.3	144.1	23.2	158.7	14.6	8.6
3.000	171.0	144.6	26.4	159.6	15.0	11.4
3.500	174.1	145.5	28.6	162.3	16.8	11.8
4.000	176.4	144.6	31.8	166.0	21.4	10.4
4.500	180.0	144.1	35.9	169.6	25.5	10.4
5.000	183.7	142.8	40.9	171.0	28.2	12.7
5.500	187.8	143.2	44.6	174.1	30.9	13.7
6.000	188.7	143.7	45.0	176.9	33.2	11.8
6.095	188.7	143.2	45.5	178.2	35.0	10.5
6.190	189.1	143.2	45.9	178.2	35.0	10.9
6.285	192.8	142.3	50.5	180.0	37.7	12.8
6.380	197.8	141.9	55.9	184.1	42.2	13.7
					Average	10.4

Table A20: Ultimate stable scour depth for Q_w of 7.5 litres/sec and D_{50} of 0.775 mm

Time (hours)	0.0			74.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	2.4	0.0	11.5
1.500	18.2	2.5	15.7	2.5	0.0	15.7
2.000	23.5	2.5	21.0	2.5	0.0	21.0
2.500	26.0	0.9	25.1	3.6	2.7	22.4
3.000	27.5	2.0	25.5	8.0	6.0	19.5
3.500	32.8	2.5	30.3	11.0	8.5	21.8
4.000	34.3	2.0	32.3	15.7	13.7	18.6
4.500	41.0	2.0	39.0	19.8	17.8	21.2
5.000	48.5	1.8	46.7	22.5	20.7	26.0
5.500	53.7	2.0	51.7	25.0	23.0	28.7
6.000	58.5	3.4	55.1	28.6	25.2	29.9
6.095	56.9	3.4	53.5	29.3	25.9	27.6
6.190	55.5	3.5	52.0	30.6	27.1	24.9
6.285	55.5	3.3	52.2	31.9	28.6	23.6
6.380	55.0	3.2	51.8	38.0	34.8	17.0
					Average	19.9

Table A21: Ultimate stable scour depth for Q_w of 8.4 litres/sec and D_{50} of 0.775 mm

Time (hours)	0.0			82.2		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.5	0.0	20.2
2.500	25.6	0.9	24.7	1.0	0.1	24.6
3.000	27.5	2.0	25.5	2.0	0.0	25.5
3.500	32.3	2.5	29.8	4.2	1.7	28.1
4.000	33.0	2.0	31.0	8.8	6.8	24.2
4.500	37.9	2.0	35.9	12.0	10.0	25.9
5.000	44.0	1.8	42.2	16.5	14.7	27.5
5.500	49.5	2.0	47.5	20.5	18.5	29.0
6.000	54.6	3.4	51.2	23.0	19.6	31.6
6.095	54.7	3.4	51.3	24.9	21.5	29.8
6.190	54.3	3.5	50.8	25.9	22.4	28.4
6.285	54.3	3.3	51.0	27.9	24.6	26.4
6.380	55.1	3.2	51.9	35.0	31.8	20.1
				Average		21.9

APPENDIX B: Storage depletion dataTable B1: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 0 – 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	152.3	5.0	1.4	152.3	5.0	1.4
1.000	157.5	146.4	11.1	155.5	9.1	2.0	155.0	8.6	2.5
1.500	161.9	146.4	15.5	160.5	14.1	1.4	159.1	12.7	2.8
2.000	166.4	146.0	20.4	163.2	17.2	3.2	161.9	15.9	4.5
2.500	167.3	144.1	23.2	166.4	22.3	0.9	166.9	22.8	0.4
3.000	171.0	144.6	26.4	167.8	23.2	3.2	167.0	22.4	4.0
3.500	174.1	145.5	28.6	173.2	27.7	0.9	171.0	25.5	3.1
4.000	176.4	144.6	31.8	176.9	32.3	-0.5	176.0	31.4	0.4
4.500	180.0	144.1	35.9	175.5	31.4	4.5	178.2	34.1	1.8
5.000	183.7	142.8	40.9	180.5	37.7	3.2	176.9	34.1	6.8
5.500	187.8	143.2	44.6	183.7	40.5	4.1	181.4	38.2	6.4
6.000	188.7	143.7	45.0	186.4	42.7	2.3	185.5	41.8	3.2
6.095	188.7	143.2	45.5	185.5	42.3	3.2	186.4	43.2	2.3
6.190	189.1	143.2	45.9	183.7	40.5	5.4	183.2	40.0	5.9
6.285	192.8	142.3	50.5	186.0	43.7	6.8	186.9	44.6	5.9
6.380	197.8	141.9	55.9	188.2	46.3	9.6	191.9	50.0	5.9
					Average	3.0			3.4

Table B2: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 1 – 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	151.4	4.1	2.3	151.9	4.6	1.8
1.000	157.5	146.4	11.1	155.5	9.1	2.0	154.6	8.2	2.9
1.500	161.9	146.4	15.5	157.7	11.3	4.2	158.2	11.8	3.7
2.000	166.4	146.0	20.4	162.7	16.7	3.7	161.4	15.4	5.0
2.500	167.3	144.1	23.2	167.3	23.2	0.0	166.0	21.9	1.3
3.000	171.0	144.6	26.4	167.3	22.7	3.7	168.7	24.1	2.3
3.500	174.1	145.5	28.6	171.9	26.4	2.2	169.6	24.1	4.5
4.000	176.4	144.6	31.8	175.5	30.9	0.9	174.6	30.0	1.8
4.500	180.0	144.1	35.9	177.8	33.7	2.2	176.9	32.8	3.1
5.000	183.7	142.8	40.9	180.5	37.7	3.2	181.0	38.2	2.7
5.500	187.8	143.2	44.6	180.5	37.3	7.3	181.4	38.2	6.4
6.000	188.7	143.7	45.0	184.6	40.9	4.1	183.2	39.5	5.5
6.095	188.7	143.2	45.5	184.1	40.9	4.6	185.5	42.3	3.2
6.190	189.1	143.2	45.9	185.0	41.8	4.1	186.4	43.2	2.7
6.285	192.8	142.3	50.5	188.2	45.9	4.6	186.9	44.6	5.9
6.380	197.8	141.9	55.9	190.0	48.1	7.8	191.0	49.1	6.8
					Average	3.3			3.5

Table B3: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 2 – 4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	151.4	4.1	2.3	150.5	3.2	3.2
1.000	157.5	146.4	11.1	154.6	8.2	2.9	153.2	6.8	4.3
1.500	161.9	146.4	15.5	156.9	10.5	5.0	156.0	9.6	5.9
2.000	166.4	146.0	20.4	159.5	13.5	6.9	159.1	13.1	7.3
2.500	167.3	144.1	23.2	165.0	20.9	2.3	163.7	19.6	3.6
3.000	171.0	144.6	26.4	166.0	21.4	5.0	164.6	20.0	6.4
3.500	174.1	145.5	28.6	169.1	23.6	5.0	167.7	22.2	6.4
4.000	176.4	144.6	31.8	171.4	26.8	5.0	171.4	26.8	5.0
4.500	180.0	144.1	35.9	173.7	29.6	6.3	173.2	29.1	6.8
5.000	183.7	142.8	40.9	177.3	34.5	6.4	175.0	32.2	8.7
5.500	187.8	143.2	44.6	181.0	37.8	6.8	177.8	34.6	10.0
6.000	188.7	143.7	45.0	182.3	38.6	6.4	181.0	37.3	7.7
6.095	188.7	143.2	45.5	183.2	40.0	5.5	182.3	39.1	6.4
6.190	189.1	143.2	45.9	184.6	41.4	4.5	182.8	39.6	6.3
6.285	192.8	142.3	50.5	185.5	43.2	7.3	185.0	42.7	7.8
6.380	197.8	141.9	55.9	189.1	47.2	8.7	187.8	45.9	10.0
Average						5.1	6.2		

Table B4: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 4 – 6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	149.6	2.3	4.1	149.6	2.3	4.1
1.000	157.5	146.4	11.1	151.0	4.6	6.5	151.0	4.6	6.5
1.500	161.9	146.4	15.5	157.8	11.4	4.1	157.3	10.9	4.6
2.000	166.4	146.0	20.4	158.7	12.7	7.7	159.1	13.1	7.3
2.500	167.3	144.1	23.2	162.3	18.2	5.0	161.9	17.8	5.4
3.000	171.0	144.6	26.4	164.6	20.0	6.4	164.6	20.0	6.4
3.500	174.1	145.5	28.6	166.9	21.4	7.2	166.0	20.5	8.1
4.000	176.4	144.6	31.8	171.4	26.8	5.0	171.4	26.8	5.0
4.500	180.0	144.1	35.9	173.0	28.9	7.0	172.8	28.7	7.2
5.000	183.7	142.8	40.9	175.0	32.2	8.7	176.4	33.6	7.3
5.500	187.8	143.2	44.6	176.9	33.7	10.9	176.4	33.2	11.4
6.000	188.7	143.7	45.0	179.1	35.4	9.6	179.1	35.4	9.6
6.095	188.7	143.2	45.5	181.9	38.7	6.8	179.6	36.4	9.1
6.190	189.1	143.2	45.9	182.8	39.6	6.3	182.3	39.1	6.8
6.285	192.8	142.3	50.5	182.8	40.5	10.0	182.3	40.0	10.5
6.380	197.8	141.9	55.9	186.3	44.4	11.5	186.0	44.1	11.8
Average						6.9	7.1		

Table B5: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 6 – 8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	149.6	2.3	4.1	149.6	2.3	4.1
1.000	157.5	146.4	11.1	150.5	4.1	7.0	150.0	3.6	7.5
1.500	161.9	146.4	15.5	156.8	10.4	5.1	156.4	10.0	5.5
2.000	166.4	146.0	20.4	158.2	12.2	8.2	157.8	11.8	8.6
2.500	167.3	144.1	23.2	162.3	18.2	5.0	161.4	17.3	5.9
3.000	171.0	144.6	26.4	164.6	20.0	6.4	164.5	19.9	6.5
3.500	174.1	145.5	28.6	165.5	20.0	8.6	165.5	20.0	8.6
4.000	176.4	144.6	31.8	170.5	25.9	5.9	169.6	25.0	6.8
4.500	180.0	144.1	35.9	173.2	29.1	6.8	173.2	29.1	6.8
5.000	183.7	142.8	40.9	176.4	33.6	7.3	176.0	33.2	7.7
5.500	187.8	143.2	44.6	176.2	33.0	11.6	176.0	32.8	11.8
6.000	188.7	143.7	45.0	178.3	34.6	10.4	177.8	34.1	10.9
6.095	188.7	143.2	45.5	180.0	36.8	8.7	181.0	37.8	7.7
6.190	189.1	143.2	45.9	181.9	38.7	7.2	181.0	37.8	8.1
6.285	192.8	142.3	50.5	182.7	40.4	10.1	182.3	40.0	10.5
6.380	197.8	141.9	55.9	186.0	44.1	11.8	186.0	44.1	11.8
				Average		7.3			7.6

Table B6: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 8 – 12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	149.6	2.3	4.1	149.6	2.3	4.1
1.000	157.5	146.4	11.1	150.0	3.6	7.5	150.0	3.6	7.5
1.500	161.9	146.4	15.5	156.0	9.6	5.9	155.0	8.6	6.9
2.000	166.4	146.0	20.4	157.8	11.8	8.6	157.8	11.8	8.6
2.500	167.3	144.1	23.2	161.0	16.9	6.3	161.0	16.9	6.3
3.000	171.0	144.6	26.4	163.7	19.1	7.3	163.2	18.6	7.8
3.500	174.1	145.5	28.6	164.6	19.1	9.5	164.6	19.1	9.5
4.000	176.4	144.6	31.8	169.6	25.0	6.8	169.6	25.0	6.8
4.500	180.0	144.1	35.9	171.9	27.8	8.1	171.9	27.8	8.1
5.000	183.7	142.8	40.9	174.6	31.8	9.1	174.6	31.8	9.1
5.500	187.8	143.2	44.6	176.0	32.8	11.8	176.0	32.8	11.8
6.000	188.7	143.7	45.0	177.8	34.1	10.9	177.8	34.1	10.9
6.095	188.7	143.2	45.5	181.0	37.8	7.7	181.0	37.8	7.7
6.190	189.1	143.2	45.9	181.0	37.8	8.1	181.0	37.8	8.1
6.285	192.8	142.3	50.5	182.3	40.0	10.5	182.3	40.0	10.5
6.380	197.8	141.9	55.9	186.0	44.1	11.8	186.0	44.1	11.8
				Average		7.9			8.0

Table B7: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 12 – 16 hours)

Time (hours)	0.0			14.42			16.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	149.6	2.3	4.1	149.6	2.3	4.1
1.000	157.5	146.4	11.1	150.0	3.6	7.5	150.5	4.1	7.0
1.500	161.9	146.4	15.5	155.0	8.6	6.9	149.6	3.2	12.3
2.000	166.4	146.0	20.4	157.8	11.8	8.6	157.8	11.8	8.6
2.500	167.3	144.1	23.2	161.0	16.9	6.3	159.6	15.5	7.7
3.000	171.0	144.6	26.4	162.5	17.9	8.5	161.9	17.3	9.1
3.500	174.1	145.5	28.6	164.6	19.1	9.5	165.5	20.0	8.6
4.000	176.4	144.6	31.8	169.6	25.0	6.8	168.2	23.6	8.2
4.500	180.0	144.1	35.9	171.5	27.4	8.5	171.4	27.3	8.6
5.000	183.7	142.8	40.9	174.6	31.8	9.1	174.6	31.8	9.1
5.500	187.8	143.2	44.6	176.0	32.8	11.8	177.3	34.1	10.5
6.000	188.7	143.7	45.0	177.8	34.1	10.9	178.7	35.0	10.0
6.095	188.7	143.2	45.5	180.5	37.3	8.2	180.0	36.8	8.7
6.190	189.1	143.2	45.9	181.0	37.8	8.1	181.4	38.2	7.7
6.285	192.8	142.3	50.5	182.3	40.0	10.5	181.9	39.6	10.9
6.380	197.8	141.9	55.9	186.0	44.1	11.8	186.4	44.5	11.4
				Average			8.1		
							8.4		

Table B8: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 16 – 29 hours)

Time (hours)	0.0			21.0			29.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	150.0	3.6	7.5	150.0	3.6	7.5
1.500	161.9	146.4	15.5	149.1	2.7	12.8	148.7	2.3	13.2
2.000	166.4	146.0	20.4	157.3	11.3	9.1	154.6	8.6	11.8
2.500	167.3	144.1	23.2	158.7	14.6	8.6	158.7	14.6	8.6
3.000	171.0	144.6	26.4	161.0	16.4	10.0	159.6	15.0	11.4
3.500	174.1	145.5	28.6	163.7	18.2	10.4	162.3	16.8	11.8
4.000	176.4	144.6	31.8	166.9	22.3	9.5	166.0	21.4	10.4
4.500	180.0	144.1	35.9	170.0	25.9	10.0	169.6	25.5	10.4
5.000	183.7	142.8	40.9	173.2	30.4	10.5	171.0	28.2	12.7
5.500	187.8	143.2	44.6	176.0	32.8	11.8	174.1	30.9	13.7
6.000	188.7	143.7	45.0	177.7	34.0	11.0	176.9	33.2	11.8
6.095	188.7	143.2	45.5	178.7	35.5	10.0	178.2	35.0	10.5
6.190	189.1	143.2	45.9	179.6	36.4	9.5	178.2	35.0	10.9
6.285	192.8	142.3	50.5	181.0	38.7	11.8	180.0	37.7	12.8
6.380	197.8	141.9	55.9	185.0	43.1	12.8	184.1	42.2	13.7
				Average			9.5		
							10.4		

Table B9: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 29 – 41 hours)

Time (hours)	0.0			34.0			41.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	149.1	2.7	8.4	149.1	2.7	8.4
1.500	161.9	146.4	15.5	148.7	2.3	13.2	148.2	1.8	13.7
2.000	166.4	146.0	20.4	153.7	7.7	12.7	153.2	7.2	13.2
2.500	167.3	144.1	23.2	158.2	14.1	9.1	157.3	13.2	10.0
3.000	171.0	144.6	26.4	159.6	15.0	11.4	159.6	15.0	11.4
3.500	174.1	145.5	28.6	162.3	16.8	11.8	161.9	16.4	12.2
4.000	176.4	144.6	31.8	164.6	20.0	11.8	164.1	19.5	12.3
4.500	180.0	144.1	35.9	167.8	23.7	12.2	167.8	23.7	12.2
5.000	183.7	142.8	40.9	170.5	27.7	13.2	170.0	27.2	13.7
5.500	187.8	143.2	44.6	174.1	30.9	13.7	173.2	30.0	14.6
6.000	188.7	143.7	45.0	176.4	32.7	12.3	176.4	32.7	12.3
6.095	188.7	143.2	45.5	177.8	34.6	10.9	177.3	34.1	11.4
6.190	189.1	143.2	45.9	179.6	36.4	9.5	178.7	35.5	10.4
6.285	192.8	142.3	50.5	181.9	39.6	10.9	180.0	37.7	12.8
6.380	197.8	141.9	55.9	185.5	43.6	12.3	185.5	43.6	12.3
Average						10.5	11.0		

Table B10: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 41 – 57 hours)

Time (hours)	0.0			45.0			57.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	149.1	2.7	8.4	148.7	2.3	8.8
1.500	161.9	146.4	15.5	148.2	1.8	13.7	148.2	1.8	13.7
2.000	166.4	146.0	20.4	152.3	6.3	14.1	151.4	5.4	15.0
2.500	167.3	144.1	23.2	156.9	12.8	10.4	156.0	11.9	11.3
3.000	171.0	144.6	26.4	158.2	13.6	12.8	156.9	12.3	14.1
3.500	174.1	145.5	28.6	161.0	15.5	13.1	161.0	15.5	13.1
4.000	176.4	144.6	31.8	164.1	19.5	12.3	164.1	19.5	12.3
4.500	180.0	144.1	35.9	166.9	22.8	13.1	166.9	22.8	13.1
5.000	183.7	142.8	40.9	170.0	27.2	13.7	169.6	26.8	14.1
5.500	187.8	143.2	44.6	172.8	29.6	15.0	172.8	29.6	15.0
6.000	188.7	143.7	45.0	175.5	31.8	13.2	175.0	31.3	13.7
6.095	188.7	143.2	45.5	176.9	33.7	11.8	176.4	33.2	12.3
6.190	189.1	143.2	45.9	177.8	34.6	11.3	179.1	35.9	10.0
6.285	192.8	142.3	50.5	180.0	37.7	12.8	179.6	37.3	13.2
6.380	197.8	141.9	55.9	184.6	42.7	13.2	184.1	42.2	13.7
Average						11.4	11.7		

Table B11: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 57 – 63 hours)

Time (hours)	0.0			60.0			63.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.8	1.4	9.7	147.8	1.4	9.7
1.500	161.9	146.4	15.5	148.2	1.8	13.7	147.8	1.4	14.1
2.000	166.4	146.0	20.4	150.5	4.5	15.9	149.6	3.6	16.8
2.500	167.3	144.1	23.2	156.0	11.9	11.3	155.5	11.4	11.8
3.000	171.0	144.6	26.4	156.4	11.8	14.6	156.0	11.4	15.0
3.500	174.1	145.5	28.6	159.1	13.6	15.0	158.7	13.2	15.4
4.000	176.4	144.6	31.8	163.7	19.1	12.7	163.2	18.6	13.2
4.500	180.0	144.1	35.9	166.9	22.8	13.1	166.4	22.3	13.6
5.000	183.7	142.8	40.9	169.6	26.8	14.1	169.1	26.3	14.6
5.500	187.8	143.2	44.6	172.3	29.1	15.5	172.3	29.1	15.5
6.000	188.7	143.7	45.0	175.0	31.3	13.7	175.0	31.3	13.7
6.095	188.7	143.2	45.5	176.4	33.2	12.3	176.9	33.7	11.8
6.190	189.1	143.2	45.9	177.3	34.1	11.8	177.3	34.1	11.8
6.285	192.8	142.3	50.5	178.7	36.4	14.1	179.6	37.3	13.2
6.380	197.8	141.9	55.9	184.6	42.7	13.2	184.1	42.2	13.7
				Average		12.1			12.3

Table B12: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 63 – 69 hours)

Time (hours)	0.0			66.0			69.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.3	0.9	10.2	147.3	0.9	10.2
1.500	161.9	146.4	15.5	148.2	1.8	13.7	147.3	0.9	14.6
2.000	166.4	146.0	20.4	149.6	3.6	16.8	149.6	3.6	16.8
2.500	167.3	144.1	23.2	154.6	10.5	12.7	153.7	9.6	13.6
3.000	171.0	144.6	26.4	155.5	10.9	15.5	155.5	10.9	15.5
3.500	174.1	145.5	28.6	158.7	13.2	15.4	158.7	13.2	15.4
4.000	176.4	144.6	31.8	162.3	17.7	14.1	161.9	17.3	14.5
4.500	180.0	144.1	35.9	166.0	21.9	14.0	165.5	21.4	14.5
5.000	183.7	142.8	40.9	168.2	25.4	15.5	168.2	25.4	15.5
5.500	187.8	143.2	44.6	171.9	28.7	15.9	171.0	27.8	16.8
6.000	188.7	143.7	45.0	175.0	31.3	13.7	174.1	30.4	14.6
6.095	188.7	143.2	45.5	176.0	32.8	12.7	176.0	32.8	12.7
6.190	189.1	143.2	45.9	176.9	33.7	12.2	176.9	33.7	12.2
6.285	192.8	142.3	50.5	179.1	36.8	13.7	179.1	36.8	13.7
6.380	197.8	141.9	55.9	184.6	42.7	13.2	184.1	42.2	13.7
				Average		12.6			12.9

Table B13: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 69 – 83 hours)

Time (hours)	0.0			80.0			83.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.3	0.9	10.2	147.3	0.9	10.2
1.500	161.9	146.4	15.5	147.3	0.9	14.6	147.3	0.9	14.6
2.000	166.4	146.0	20.4	149.1	3.1	17.3	149.1	3.1	17.3
2.500	167.3	144.1	23.2	154.1	10.0	13.2	153.2	9.1	14.1
3.000	171.0	144.6	26.4	155.0	10.4	16.0	155.0	10.4	16.0
3.500	174.1	145.5	28.6	158.7	13.2	15.4	158.7	13.2	15.4
4.000	176.4	144.6	31.8	161.9	17.3	14.5	161.9	17.3	14.5
4.500	180.0	144.1	35.9	165.5	21.4	14.5	165.5	21.4	14.5
5.000	183.7	142.8	40.9	168.7	25.9	15.0	169.6	26.8	14.1
5.500	187.8	143.2	44.6	171.0	27.8	16.8	171.0	27.8	16.8
6.000	188.7	143.7	45.0	173.7	30.0	15.0	173.2	29.5	15.5
6.095	188.7	143.2	45.5	175.0	31.8	13.7	175.5	32.3	13.2
6.190	189.1	143.2	45.9	176.9	33.7	12.2	176.9	33.7	12.2
6.285	192.8	142.3	50.5	178.7	36.4	14.1	177.8	35.5	15.0
6.380	197.8	141.9	55.9	184.1	42.2	13.7	183.7	41.8	14.1
				Average		13.0			13.1

Table B14: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 83 – 89 hours)

Time (hours)	0.0			86.0			89.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.3	0.9	10.2	147.3	0.9	10.2
1.500	161.9	146.4	15.5	147.3	0.9	14.6	147.3	0.9	14.6
2.000	166.4	146.0	20.4	148.7	2.7	17.7	148.7	2.7	17.7
2.500	167.3	144.1	23.2	153.7	9.6	13.6	152.8	8.7	14.5
3.000	171.0	144.6	26.4	155.0	10.4	16.0	154.1	9.5	16.9
3.500	174.1	145.5	28.6	158.7	13.2	15.4	158.7	13.2	15.4
4.000	176.4	144.6	31.8	161.9	17.3	14.5	161.4	16.8	15.0
4.500	180.0	144.1	35.9	165.5	21.4	14.5	165.0	20.9	15.0
5.000	183.7	142.8	40.9	169.1	26.3	14.6	169.1	26.3	14.6
5.500	187.8	143.2	44.6	171.4	28.2	16.4	171.4	28.2	16.4
6.000	188.7	143.7	45.0	172.3	28.6	16.4	173.7	30.0	15.0
6.095	188.7	143.2	45.5	174.6	31.4	14.1	175.0	31.8	13.7
6.190	189.1	143.2	45.9	176.9	33.7	12.2	176.9	33.7	12.2
6.285	192.8	142.3	50.5	177.3	35.0	15.5	177.3	35.0	15.5
6.380	197.8	141.9	55.9	183.2	41.3	14.6	183.2	41.3	14.6
				Average		13.3			13.3

Table B15: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 89 – 103 hours)

Time (hours)	0.0			92.0			103.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.3	0.9	10.2	147.3	0.9	10.2
1.500	161.9	146.4	15.5	147.3	0.9	14.6	147.3	0.9	14.6
2.000	166.4	146.0	20.4	147.8	1.8	18.6	147.8	1.8	18.6
2.500	167.3	144.1	23.2	152.8	8.7	14.5	152.8	8.7	14.5
3.000	171.0	144.6	26.4	155.0	10.4	16.0	154.6	10.0	16.4
3.500	174.1	145.5	28.6	157.8	12.3	16.3	157.8	12.3	16.3
4.000	176.4	144.6	31.8	161.4	16.8	15.0	161.4	16.8	15.0
4.500	180.0	144.1	35.9	165.0	20.9	15.0	164.1	20.0	15.9
5.000	183.7	142.8	40.9	169.1	26.3	14.6	168.2	25.4	15.5
5.500	187.8	143.2	44.6	171.0	27.8	16.8	170.5	27.3	17.3
6.000	188.7	143.7	45.0	174.1	30.4	14.6	174.1	30.4	14.6
6.095	188.7	143.2	45.5	174.6	31.4	14.1	174.6	31.4	14.1
6.190	189.1	143.2	45.9	177.3	34.1	11.8	176.4	33.2	12.7
6.285	192.8	142.3	50.5	178.2	35.9	14.6	178.2	35.9	14.6
6.380	197.8	141.9	55.9	182.8	40.9	15.0	183.2	41.3	14.6
				Average			13.4		
							13.6		

Table B16: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 0.775 mm; Measuring times range: 103 – 109 hours)

Time (hours)	0.0			106.0			109.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	149.1	149.1	0.0	149.1	0.0	0.0	149.1	0.0	0.0
0.500	153.7	147.3	6.4	148.2	0.9	5.5	148.2	0.9	5.5
1.000	157.5	146.4	11.1	147.3	0.9	10.2	147.3	0.9	10.2
1.500	161.9	146.4	15.5	147.3	0.9	14.6	147.3	0.9	14.6
2.000	166.4	146.0	20.4	147.8	1.8	18.6	147.8	1.8	18.6
2.500	167.3	144.1	23.2	151.4	7.3	15.9	151.4	7.3	15.9
3.000	171.0	144.6	26.4	154.1	9.5	16.9	154.1	9.5	16.9
3.500	174.1	145.5	28.6	157.3	11.8	16.8	157.2	11.7	16.9
4.000	176.4	144.6	31.8	161.4	16.8	15.0	161.4	16.8	15.0
4.500	180.0	144.1	35.9	164.1	20.0	15.9	164.1	20.0	15.9
5.000	183.7	142.8	40.9	168.2	25.4	15.5	168.2	25.4	15.5
5.500	187.8	143.2	44.6	170.5	27.3	17.3	170.5	27.3	17.3
6.000	188.7	143.7	45.0	173.7	30.0	15.0	173.7	30.0	15.0
6.095	188.7	143.2	45.5	174.6	31.4	14.1	175.2	32.0	13.5
6.190	189.1	143.2	45.9	176.4	33.2	12.7	176.8	33.6	12.3
6.285	192.8	142.3	50.5	178.2	35.9	14.6	178.4	36.1	14.4
6.380	197.8	141.9	55.9	182.8	40.9	15.0	183.8	41.9	14.0
				Average			13.7		
							13.6		

Table B17: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 0 – 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	11.6	8.6	0.2	11.3	8.3	0.5
1.000	13.9	2.4	11.5	13.5	11.1	0.4	13.2	10.8	0.7
1.500	18.2	2.5	15.7	17.8	15.3	0.4	15.2	12.7	3.0
2.000	23.5	2.5	21.0	21.0	18.5	2.5	19.8	17.3	3.7
2.500	26.0	0.9	25.1	24.8	23.9	1.2	23.3	22.4	2.7
3.000	27.5	2.0	25.5	26.5	24.5	1.0	26.7	24.7	0.8
3.500	32.8	2.5	30.3	27.2	24.7	5.6	30.0	27.5	2.8
4.000	34.3	2.0	32.3	34.2	32.2	0.1	28.5	26.5	5.8
4.500	41.0	2.0	39.0	35.5	33.5	5.5	32.0	30.0	9.0
5.000	48.5	1.8	46.7	36.0	34.2	12.5	36.0	34.2	12.5
5.500	53.7	2.0	51.7	38.8	36.8	14.9	37.6	35.6	16.1
6.000	58.5	3.4	55.1	43.2	39.8	15.3	42.0	38.6	16.5
6.095	56.9	3.4	53.5	42.6	39.2	14.3	42.2	38.8	14.7
6.190	55.5	3.5	52.0	44.3	40.8	11.2	42.8	39.3	12.7
6.285	55.5	3.3	52.2	42.1	38.8	13.4	45.0	41.7	10.5
6.380	55.0	3.2	51.8	45.2	42.0	9.8	43.2	40.0	11.8
				Average		6.4			7.3

Table B18: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 1 – 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	10.3	7.3	1.5	9.1	6.1	2.7
1.000	13.9	2.4	11.5	11.9	9.5	2.0	11.3	8.9	2.6
1.500	18.2	2.5	15.7	15.0	12.5	3.2	13.7	11.2	4.5
2.000	23.5	2.5	21.0	18.5	16.0	5.0	17.9	15.4	5.6
2.500	26.0	0.9	25.1	23.3	22.4	2.7	22.8	21.9	3.2
3.000	27.5	2.0	25.5	26.3	24.3	1.2	25.7	23.7	1.8
3.500	32.8	2.5	30.3	28.5	26.0	4.3	27.9	25.4	4.9
4.000	34.3	2.0	32.3	28.2	26.2	6.1	29.5	27.5	4.8
4.500	41.0	2.0	39.0	34.2	32.2	6.8	33.5	31.5	7.5
5.000	48.5	1.8	46.7	34.5	32.7	14.0	33.6	31.8	14.9
5.500	53.7	2.0	51.7	35.0	33.0	18.7	38.0	36.0	15.7
6.000	58.5	3.4	55.1	37.3	33.9	21.2	37.8	34.4	20.7
6.095	56.9	3.4	53.5	40.0	36.6	16.9	38.4	35.0	18.5
6.190	55.5	3.5	52.0	41.4	37.9	14.1	39.2	35.7	16.3
6.285	55.5	3.3	52.2	43.0	39.7	12.5	38.5	35.2	17.0
6.380	55.0	3.2	51.8	45.0	41.8	10.0	42.7	39.5	12.3
				Average		8.2			9.0

Table B19: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 2 – 4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	8.3	5.3	3.5	6.9	3.9	4.9
1.000	13.9	2.4	11.5	10.0	7.6	3.9	8.9	6.5	5.0
1.500	18.2	2.5	15.7	12.4	9.9	5.8	11.2	8.7	7.0
2.000	23.5	2.5	21.0	15.6	13.1	7.9	15.6	13.1	7.9
2.500	26.0	0.9	25.1	20.0	19.1	6.0	18.9	18.0	7.1
3.000	27.5	2.0	25.5	24.0	22.0	3.5	23.4	21.4	4.1
3.500	32.8	2.5	30.3	26.3	23.8	6.5	25.2	22.7	7.6
4.000	34.3	2.0	32.3	30.5	28.5	3.8	30.0	28.0	4.3
4.500	41.0	2.0	39.0	31.1	29.1	9.9	30.5	28.5	10.5
5.000	48.5	1.8	46.7	35.0	33.2	13.5	34.1	32.3	14.4
5.500	53.7	2.0	51.7	36.0	34.0	17.7	38.0	36.0	15.7
6.000	58.5	3.4	55.1	38.6	35.2	19.9	37.3	33.9	21.2
6.095	56.9	3.4	53.5	38.4	35.0	18.5	37.5	34.1	19.4
6.190	55.5	3.5	52.0	39.4	35.9	16.1	38.9	35.4	16.6
6.285	55.5	3.3	52.2	42.1	38.8	13.4	40.2	36.9	15.3
6.380	55.0	3.2	51.8	42.2	39.0	12.8	42.5	39.3	12.5
Average						9.6	10.2		

Table B20: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 4 – 6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	5.9	2.9	5.9	5.9	2.9	5.9
1.000	13.9	2.4	11.5	8.0	5.6	5.9	7.3	4.9	6.6
1.500	18.2	2.5	15.7	9.9	7.4	8.3	9.3	6.8	8.9
2.000	23.5	2.5	21.0	14.5	12.0	9.0	14.5	12.0	9.0
2.500	26.0	0.9	25.1	18.2	17.3	7.8	17.6	16.7	8.4
3.000	27.5	2.0	25.5	22.0	20.0	5.5	20.8	18.8	6.7
3.500	32.8	2.5	30.3	24.8	22.3	8.0	23.8	21.3	9.0
4.000	34.3	2.0	32.3	27.5	25.5	6.8	28.0	26.0	6.3
4.500	41.0	2.0	39.0	31.9	29.9	9.1	29.0	27.0	12.0
5.000	48.5	1.8	46.7	33.1	31.3	15.4	33.1	31.3	15.4
5.500	53.7	2.0	51.7	37.9	35.9	15.8	35.5	33.5	18.2
6.000	58.5	3.4	55.1	39.3	35.9	19.2	38.5	35.1	20.0
6.095	56.9	3.4	53.5	38.5	35.1	18.4	39.9	36.5	17.0
6.190	55.5	3.5	52.0	37.9	34.4	17.6	41.4	37.9	14.1
6.285	55.5	3.3	52.2	38.9	35.6	16.6	38.3	35.0	17.2
6.380	55.0	3.2	51.8	40.5	37.3	14.5	40.2	37.0	14.8
Average						10.8	11.1		

Table B21: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 6 – 8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	5.4	2.4	6.4	3.5	0.5	8.3
1.000	13.9	2.4	11.5	6.3	3.9	7.6	5.5	3.1	8.4
1.500	18.2	2.5	15.7	9.1	6.6	9.1	8.3	5.8	9.9
2.000	23.5	2.5	21.0	13.5	11.0	10.0	13.3	10.8	10.2
2.500	26.0	0.9	25.1	16.0	15.1	10.0	16.0	15.1	10.0
3.000	27.5	2.0	25.5	20.5	18.5	7.0	19.9	17.9	7.6
3.500	32.8	2.5	30.3	22.6	20.1	10.2	22.0	19.5	10.8
4.000	34.3	2.0	32.3	26.1	24.1	8.2	26.1	24.1	8.2
4.500	41.0	2.0	39.0	29.9	27.9	11.1	29.3	27.3	11.7
5.000	48.5	1.8	46.7	33.5	31.7	15.0	31.2	29.4	17.3
5.500	53.7	2.0	51.7	33.5	31.5	20.2	34.0	32.0	19.7
6.000	58.5	3.4	55.1	36.7	33.3	21.8	39.0	35.6	19.5
6.095	56.9	3.4	53.5	37.5	34.1	19.4	39.6	36.2	17.3
6.190	55.5	3.5	52.0	38.7	35.2	16.8	40.5	37.0	15.0
6.285	55.5	3.3	52.2	39.6	36.3	15.9	40.5	37.2	15.0
6.380	55.0	3.2	51.8	43.2	40.0	11.8	42.2	39.0	12.8
Average						11.8	11.9		

Table B22: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 8 – 12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	5.5	3.1	8.4	4.0	1.6	9.9
1.500	18.2	2.5	15.7	7.0	4.5	11.2	6.3	3.8	11.9
2.000	23.5	2.5	21.0	11.6	9.1	11.9	9.0	6.5	14.5
2.500	26.0	0.9	25.1	15.0	14.1	11.0	14.0	13.1	12.0
3.000	27.5	2.0	25.5	18.7	16.7	8.8	17.9	15.9	9.6
3.500	32.8	2.5	30.3	21.7	19.2	11.1	20.6	18.1	12.2
4.000	34.3	2.0	32.3	25.0	23.0	9.3	24.6	22.6	9.7
4.500	41.0	2.0	39.0	28.6	26.6	12.4	28.0	26.0	13.0
5.000	48.5	1.8	46.7	28.6	26.8	19.9	28.6	26.8	19.9
5.500	53.7	2.0	51.7	32.7	30.7	21.0	32.7	30.7	21.0
6.000	58.5	3.4	55.1	36.0	32.6	22.5	36.0	32.6	22.5
6.095	56.9	3.4	53.5	37.0	33.6	19.9	36.7	33.3	20.2
6.190	55.5	3.5	52.0	38.0	34.5	17.5	37.3	33.8	18.2
6.285	55.5	3.3	52.2	39.5	36.2	16.0	37.8	34.5	17.7
6.380	55.0	3.2	51.8	42.2	39.0	12.8	41.2	38.0	13.8
Average						13.1	13.8		

Table B23: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 12 – 24 hours)

Time (hours)	0.0			15.00			24.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	3.7	1.3	10.2	2.4	0.0	11.5
1.500	18.2	2.5	15.7	4.9	2.4	13.3	4.2	1.7	14.0
2.000	23.5	2.5	21.0	8.6	6.1	14.9	6.9	4.4	16.6
2.500	26.0	0.9	25.1	13.0	12.1	13.0	9.5	8.6	16.5
3.000	27.5	2.0	25.5	16.8	14.8	10.7	13.9	11.9	13.6
3.500	32.8	2.5	30.3	19.3	16.8	13.5	17.6	15.1	15.2
4.000	34.3	2.0	32.3	23.3	21.3	11.0	21.0	19.0	13.3
4.500	41.0	2.0	39.0	27.6	25.6	13.4	24.6	22.6	16.4
5.000	48.5	1.8	46.7	29.9	28.1	18.6	28.2	26.4	20.3
5.500	53.7	2.0	51.7	30.6	28.6	23.1	30.3	28.3	23.4
6.000	58.5	3.4	55.1	34.6	31.2	23.9	33.2	29.8	25.3
6.095	56.9	3.4	53.5	35.3	31.9	21.6	34.3	30.9	22.6
6.190	55.5	3.5	52.0	36.3	32.8	19.2	35.2	31.7	20.3
6.285	55.5	3.3	52.2	37.6	34.3	17.9	36.4	33.1	19.1
6.380	55.0	3.2	51.8	40.5	37.3	14.5	40.5	37.3	14.5
Average						14.6	16.0		

Table B24: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 24 – 38 hours)

Time (hours)	0.0			30.0			38.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	2.4	0.0	11.5	2.4	0.0	11.5
1.500	18.2	2.5	15.7	2.5	0.0	15.7	2.5	0.0	15.7
2.000	23.5	2.5	21.0	5.4	2.9	18.1	3.0	0.5	20.5
2.500	26.0	0.9	25.1	8.6	7.7	17.4	6.8	5.9	19.2
3.000	27.5	2.0	25.5	12.7	10.7	14.8	10.5	8.5	17.0
3.500	32.8	2.5	30.3	15.9	13.4	16.9	14.1	11.6	18.7
4.000	34.3	2.0	32.3	20.0	18.0	14.3	18.1	16.1	16.2
4.500	41.0	2.0	39.0	23.0	21.0	18.0	22.2	20.2	18.8
5.000	48.5	1.8	46.7	26.3	24.5	22.2	25.9	24.1	22.6
5.500	53.7	2.0	51.7	29.7	27.7	24.0	28.9	26.9	24.8
6.000	58.5	3.4	55.1	33.0	29.6	25.5	31.0	27.6	27.5
6.095	56.9	3.4	53.5	34.0	30.6	22.9	31.2	27.8	25.7
6.190	55.5	3.5	52.0	34.7	31.2	20.8	32.3	28.8	23.2
6.285	55.5	3.3	52.2	35.9	32.6	19.6	34.6	31.3	20.9
6.380	55.0	3.2	51.8	40.1	36.9	14.9	40.1	36.9	14.9
Average						16.8	18.0		

Table B25: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 38 – 55 hours)

Time (hours)	0.0			49.0			55.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8	3	0.0	8.8
1.000	13.9	2.4	11.5	2.4	0.0	11.5	2.4	0.0	11.5
1.500	18.2	2.5	15.7	2.5	0.0	15.7	2.5	0.0	15.7
2.000	23.5	2.5	21.0	3.0	0.5	20.5	2.5	0.0	21.0
2.500	26.0	0.9	25.1	6.4	5.5	19.6	5.4	4.5	20.6
3.000	27.5	2.0	25.5	9.1	7.1	18.4	8.1	6.1	19.4
3.500	32.8	2.5	30.3	13.8	11.3	19.0	12.0	9.5	20.8
4.000	34.3	2.0	32.3	17.3	15.3	17.0	16.6	14.6	17.7
4.500	41.0	2.0	39.0	21.3	19.3	19.7	19.5	17.5	21.5
5.000	48.5	1.8	46.7	23.6	21.8	24.9	22.3	20.5	26.2
5.500	53.7	2.0	51.7	27.5	25.5	26.2	26.0	24.0	27.7
6.000	58.5	3.4	55.1	31.0	27.6	27.5	29.7	26.3	28.8
6.095	56.9	3.4	53.5	32.0	28.6	24.9	30.3	26.9	26.6
6.190	55.5	3.5	52.0	32.9	29.4	22.6	31.5	28.0	24.0
6.285	55.5	3.3	52.2	32.8	29.5	22.7	32.8	29.5	22.7
6.380	55.0	3.2	51.8	39.2	36.0	15.8	39.1	35.9	15.9
Average						18.5	19.3		

Table B26: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 55 – 74 hours)

Time (hours)	0.0			61.0			74.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	2.4	0.0	11.5	2.4	0.0	11.5
1.500	18.2	2.5	15.7	2.5	0.0	15.7	2.5	0.0	15.7
2.000	23.5	2.5	21.0	2.5	0.0	21.0	2.5	0.0	21.0
2.500	26.0	0.9	25.1	3.7	2.8	22.3	3.6	2.7	22.4
3.000	27.5	2.0	25.5	8.0	6.0	19.5	8.0	6.0	19.5
3.500	32.8	2.5	30.3	11.9	9.4	20.9	11.0	8.5	21.8
4.000	34.3	2.0	32.3	16.6	14.6	17.7	15.7	13.7	18.6
4.500	41.0	2.0	39.0	19.5	17.5	21.5	19.8	17.8	21.2
5.000	48.5	1.8	46.7	23.0	21.2	25.5	22.5	20.7	26.0
5.500	53.7	2.0	51.7	27.0	25.0	26.7	25.0	23.0	28.7
6.000	58.5	3.4	55.1	29.5	26.1	29.0	28.6	25.2	29.9
6.095	56.9	3.4	53.5	30.3	26.9	26.6	29.3	25.9	27.6
6.190	55.5	3.5	52.0	30.5	27.0	25.0	30.6	27.1	24.9
6.285	55.5	3.3	52.2	31.5	28.2	24.0	31.9	28.6	23.6
6.380	55.0	3.2	51.8	38.4	35.2	16.6	38.0	34.8	17.0
Average						19.5	19.9		

Table B27: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 0.775 mm; Measuring times range: 74 – 86 hours)

Time (hours)	0.0			86.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.8	3.0	8.8	3.0	0.0	8.8
1.000	13.9	2.4	11.5	2.4	0.0	11.5
1.500	18.2	2.5	15.7	2.5	0.0	15.7
2.000	23.5	2.5	21.0	2.5	0.0	21.0
2.500	26.0	0.9	25.1	3.2	2.3	22.8
3.000	27.5	2.0	25.5	6.8	4.8	20.7
3.500	32.8	2.5	30.3	11.8	9.3	21.0
4.000	34.3	2.0	32.3	13.7	11.7	20.6
4.500	41.0	2.0	39.0	18.0	16.0	23.0
5.000	48.5	1.8	46.7	22.7	20.9	25.8
5.500	53.7	2.0	51.7	25.0	23.0	28.7
6.000	58.5	3.4	55.1	29.8	26.4	28.7
6.095	56.9	3.4	53.5	30.0	26.6	26.9
6.190	55.5	3.5	52.0	30.5	27.0	25.0
6.285	55.5	3.3	52.2	32.3	29.0	23.2
6.380	55.0	3.2	51.8	37.5	34.3	17.5
Average						20.1

Table B28: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 0 - 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	10.0	7.0	1.1	8.8	5.8	2.3
1.000	12.4	2.4	10.0	10.9	8.5	1.5	10.9	8.5	1.5
1.500	16.1	2.5	13.6	13.9	11.4	2.2	12.9	10.4	3.2
2.000	22.7	2.5	20.2	17.3	14.8	5.4	15.5	13.0	7.2
2.500	25.6	0.9	24.7	24.7	23.8	0.9	20.9	20.0	4.7
3.000	27.5	2.0	25.5	26.9	24.9	0.6	25.0	23.0	2.5
3.500	32.3	2.5	29.8	28.5	26.0	3.8	29.1	26.6	3.2
4.000	33.0	2.0	31.0	29.7	27.7	3.3	29.5	27.5	3.5
4.500	37.9	2.0	35.9	35.0	33.0	2.9	32.6	30.6	5.3
5.000	44.0	1.8	42.2	32.5	30.7	11.5	35.2	33.4	8.8
5.500	49.5	2.0	47.5	36.8	34.8	12.7	36.7	34.7	12.8
6.000	54.6	3.4	51.2	38.0	34.6	16.6	38.7	35.3	15.9
6.095	54.7	3.4	51.3	39.5	36.1	15.2	36.4	33.0	18.3
6.190	54.3	3.5	50.8	40.9	37.4	13.4	39.4	35.9	14.9
6.285	54.3	3.3	51.0	42.2	38.9	12.1	41.0	37.7	13.3
6.380	55.1	3.2	51.9	40.9	37.7	14.2	45.5	42.3	9.6
Average						6.9	7.5		

Table B29: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 1 - 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	7.3	4.3	3.8	5.9	2.9	5.2
1.000	12.4	2.4	10.0	9.8	7.4	2.6	8.8	6.4	3.6
1.500	16.1	2.5	13.6	13.4	10.9	2.7	12.2	9.7	3.9
2.000	22.7	2.5	20.2	14.5	12.0	8.2	14.5	12.0	8.2
2.500	25.6	0.9	24.7	19.1	18.2	6.5	17.0	16.1	8.6
3.000	27.5	2.0	25.5	23.3	21.3	4.2	22.3	20.3	5.2
3.500	32.3	2.5	29.8	28.7	26.2	3.6	26.2	23.7	6.1
4.000	33.0	2.0	31.0	31.2	29.2	1.8	30.3	28.3	2.7
4.500	37.9	2.0	35.9	31.4	29.4	6.5	33.1	31.1	4.8
5.000	44.0	1.8	42.2	36.3	34.5	7.7	33.2	31.4	10.8
5.500	49.5	2.0	47.5	33.8	31.8	15.7	36.0	34.0	13.5
6.000	54.6	3.4	51.2	37.7	34.3	16.9	39.4	36.0	15.2
6.095	54.7	3.4	51.3	38.2	34.8	16.5	34.8	31.4	19.9
6.190	54.3	3.5	50.8	37.8	34.3	16.5	37.3	33.8	17.0
6.285	54.3	3.3	51.0	41.2	37.9	13.1	40.0	36.7	14.3
6.380	55.1	3.2	51.9	45.2	42.0	9.9	42.1	38.9	13.0
				Average		8.0			8.9

Table B30: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 2 - 4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	7.4	5.0	5.0	5.9	3.5	6.5
1.500	16.1	2.5	13.6	10.7	8.2	5.4	9.4	6.9	6.7
2.000	22.7	2.5	20.2	12.9	10.4	9.8	11.2	8.7	11.5
2.500	25.6	0.9	24.7	16.8	15.9	8.8	15.1	14.2	10.5
3.000	27.5	2.0	25.5	21.8	19.8	5.7	19.2	17.2	8.3
3.500	32.3	2.5	29.8	22.7	20.2	9.6	22.6	20.1	9.7
4.000	33.0	2.0	31.0	26.5	24.5	6.5	26.5	24.5	6.5
4.500	37.9	2.0	35.9	30.5	28.5	7.4	29.0	27.0	8.9
5.000	44.0	1.8	42.2	35.9	34.1	8.1	28.8	27.0	15.2
5.500	49.5	2.0	47.5	36.0	34.0	13.5	30.9	28.9	18.6
6.000	54.6	3.4	51.2	37.5	34.1	17.1	36.7	33.3	17.9
6.095	54.7	3.4	51.3	38.9	35.5	15.8	37.4	34.0	17.3
6.190	54.3	3.5	50.8	37.7	34.2	16.6	38.7	35.2	15.6
6.285	54.3	3.3	51.0	37.7	34.4	16.6	41.3	38.0	13.0
6.380	55.1	3.2	51.9	40.4	37.2	14.7	43.4	40.2	11.7
				Average		9.9			10.9

Table B31: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 4 - 6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	3.7	1.3	8.7	3.3	0.9	9.1
1.500	16.1	2.5	13.6	8.0	5.5	8.1	7.0	4.5	9.1
2.000	22.7	2.5	20.2	9.5	7.0	13.2	8.5	6.0	14.2
2.500	25.6	0.9	24.7	13.8	12.9	11.8	13.2	12.3	12.4
3.000	27.5	2.0	25.5	18.4	16.4	9.1	16.9	14.9	10.6
3.500	32.3	2.5	29.8	22.0	19.5	10.3	21.6	19.1	10.7
4.000	33.0	2.0	31.0	25.5	23.5	7.5	25.5	23.5	7.5
4.500	37.9	2.0	35.9	28.5	26.5	9.4	27.8	25.8	10.1
5.000	44.0	1.8	42.2	32.2	30.4	11.8	31.7	29.9	12.3
5.500	49.5	2.0	47.5	33.2	31.2	16.3	32.5	30.5	17.0
6.000	54.6	3.4	51.2	33.2	29.8	21.4	37.5	34.1	17.1
6.095	54.7	3.4	51.3	33.8	30.4	20.9	39.2	35.8	15.5
6.190	54.3	3.5	50.8	33.7	30.2	20.6	38.8	35.3	15.5
6.285	54.3	3.3	51.0	35.3	32.0	19.0	36.7	33.4	17.6
6.380	55.1	3.2	51.9	39.1	35.9	16.0	39.9	36.7	15.2
				Average			12.5		
							11.9		

Table B32: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 6 - 8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	5.6	3.1	10.5	5.0	2.5	11.1
2.000	22.7	2.5	20.2	7.0	4.5	15.7	6.4	3.9	16.3
2.500	25.6	0.9	24.7	11.7	10.8	13.9	10.5	9.6	15.1
3.000	27.5	2.0	25.5	16.2	14.2	11.3	15.0	13.0	12.5
3.500	32.3	2.5	29.8	19.3	16.8	13.0	19.0	16.5	13.3
4.000	33.0	2.0	31.0	23.5	21.5	9.5	22.7	20.7	10.3
4.500	37.9	2.0	35.9	27.4	25.4	10.5	27.0	25.0	10.9
5.000	44.0	1.8	42.2	29.6	27.8	14.4	29.0	27.2	15.0
5.500	49.5	2.0	47.5	34.9	32.9	14.6	32.4	30.4	17.1
6.000	54.6	3.4	51.2	33.6	30.2	21.0	36.8	33.4	17.8
6.095	54.7	3.4	51.3	34.8	31.4	19.9	34.9	31.5	19.8
6.190	54.3	3.5	50.8	35.9	32.4	18.4	35.0	31.5	19.3
6.285	54.3	3.3	51.0	37.3	34.0	17.0	36.2	32.9	18.1
6.380	55.1	3.2	51.9	42.0	38.8	13.1	40.7	37.5	14.4
				Average			13.0		
							13.5		

Table B33: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 8 - 13 hours)

Time (hours)	0.0			10.0			13.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	4.4	1.9	11.7	3.0	0.5	13.1
2.000	22.7	2.5	20.2	4.0	1.5	18.7	3.2	0.7	19.5
2.500	25.6	0.9	24.7	9.3	8.4	16.3	7.7	6.8	17.9
3.000	27.5	2.0	25.5	13.1	11.1	14.4	11.0	9.0	16.5
3.500	32.3	2.5	29.8	18.0	15.5	14.3	15.7	13.2	16.6
4.000	33.0	2.0	31.0	21.0	19.0	12.0	18.5	16.5	14.5
4.500	37.9	2.0	35.9	25.3	23.3	12.6	23.9	21.9	14.0
5.000	44.0	1.8	42.2	28.0	26.2	16.0	26.6	24.8	17.4
5.500	49.5	2.0	47.5	31.0	29.0	18.5	29.9	27.9	19.6
6.000	54.6	3.4	51.2	35.3	31.9	19.3	32.3	28.9	22.3
6.095	54.7	3.4	51.3	36.0	32.6	18.7	33.2	29.8	21.5
6.190	54.3	3.5	50.8	37.0	33.5	17.3	34.7	31.2	19.6
6.285	54.3	3.3	51.0	37.6	34.3	16.7	36.2	32.9	18.1
6.380	55.1	3.2	51.9	41.7	38.5	13.4	40.2	37.0	14.9
				Average		14.0	15.5		

Table B34: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 13 - 27 hours)

Time (hours)	0.0			21.00			27.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.7	0.2	20.0	2.5	0.0	20.2
2.500	25.6	0.9	24.7	5.2	4.3	20.4	3.6	2.7	22.0
3.000	27.5	2.0	25.5	8.0	6.0	19.5	6.3	4.3	21.2
3.500	32.3	2.5	29.8	11.6	9.1	20.7	11.2	8.7	21.1
4.000	33.0	2.0	31.0	15.5	13.5	17.5	14.2	12.2	18.8
4.500	37.9	2.0	35.9	20.0	18.0	17.9	18.2	16.2	19.7
5.000	44.0	1.8	42.2	23.9	22.1	20.1	21.9	20.1	22.1
5.500	49.5	2.0	47.5	27.3	25.3	22.2	25.0	23.0	24.5
6.000	54.6	3.4	51.2	31.0	27.6	23.6	29.7	26.3	24.9
6.095	54.7	3.4	51.3	31.2	27.8	23.5	29.7	26.3	25.0
6.190	54.3	3.5	50.8	31.8	28.3	22.5	30.5	27.0	23.8
6.285	54.3	3.3	51.0	33.3	30.0	21.0	31.5	28.2	22.8
6.380	55.1	3.2	51.9	38.7	35.5	16.4	37.3	34.1	17.8
				Average		17.5	18.6		

Table B35: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 27 - 45 hours)

Time (hours)	0.0			35.0			45.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.5	0.0	20.2	2.5	0.0	20.2
2.500	25.6	0.9	24.7	2.3	1.4	23.3	1.3	0.4	24.3
3.000	27.5	2.0	25.5	5.0	3.0	22.5	4.1	2.1	23.4
3.500	32.3	2.5	29.8	9.2	6.7	23.1	7.6	5.1	24.7
4.000	33.0	2.0	31.0	12.0	10.0	21.0	11.2	9.2	21.8
4.500	37.9	2.0	35.9	16.3	14.3	21.6	15.0	13.0	22.9
5.000	44.0	1.8	42.2	21.0	19.2	23.0	18.5	16.7	25.5
5.500	49.5	2.0	47.5	24.1	22.1	25.4	21.9	19.9	27.6
6.000	54.6	3.4	51.2	27.2	23.8	27.4	26.4	23.0	28.2
6.095	54.7	3.4	51.3	28.0	24.6	26.7	28.0	24.6	26.7
6.190	54.3	3.5	50.8	29.0	25.5	25.3	28.7	25.2	25.6
6.285	54.3	3.3	51.0	31.3	28.0	23.0	30.5	27.2	23.8
6.380	55.1	3.2	51.9	37.3	34.1	17.8	36.4	33.2	18.7
Average						19.5	20.3		

Table B36: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 45 - 59 hours)

Time (hours)	0.0			51.0			59.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.5	0.0	20.2	2.5	0.0	20.2
2.500	25.6	0.9	24.7	1.0	0.1	24.6	1.0	0.1	24.6
3.000	27.5	2.0	25.5	3.3	1.3	24.2	3.0	1.0	24.5
3.500	32.3	2.5	29.8	6.9	4.4	25.4	6.2	3.7	26.1
4.000	33.0	2.0	31.0	11.4	9.4	21.6	10.5	8.5	22.5
4.500	37.9	2.0	35.9	14.1	12.1	23.8	14.2	12.2	23.7
5.000	44.0	1.8	42.2	18.9	17.1	25.1	18.4	16.6	25.6
5.500	49.5	2.0	47.5	22.0	20.0	27.5	21.4	19.4	28.1
6.000	54.6	3.4	51.2	25.5	22.1	29.1	25.0	21.6	29.6
6.095	54.7	3.4	51.3	26.4	23.0	28.3	26.1	22.7	28.6
6.190	54.3	3.5	50.8	28.3	24.8	26.0	27.2	23.7	27.1
6.285	54.3	3.3	51.0	30.1	26.8	24.2	28.9	25.6	25.4
6.380	55.1	3.2	51.9	36.0	32.8	19.1	37.2	34.0	17.9
Average						20.6	20.9		

Table B37: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 59 – 76.2 hours)

Time (hours)	0.0			68.0			76.2		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.5	0.0	20.2	2.5	0.0	20.2
2.500	25.6	0.9	24.7	1.0	0.1	24.6	1.0	0.1	24.6
3.000	27.5	2.0	25.5	3.0	1.0	24.5	2.0	0.0	25.5
3.500	32.3	2.5	29.8	5.0	2.5	27.3	4.8	2.3	27.5
4.000	33.0	2.0	31.0	9.1	7.1	23.9	9.0	7.0	24.0
4.500	37.9	2.0	35.9	12.3	10.3	25.6	12.0	10.0	25.9
5.000	44.0	1.8	42.2	16.9	15.1	27.1	16.3	14.5	27.7
5.500	49.5	2.0	47.5	21.0	19.0	28.5	21.0	19.0	28.5
6.000	54.6	3.4	51.2	24.9	21.5	29.7	24.3	20.9	30.3
6.095	54.7	3.4	51.3	25.4	22.0	29.3	25.4	22.0	29.3
6.190	54.3	3.5	50.8	26.8	23.3	27.5	26.8	23.3	27.5
6.285	54.3	3.3	51.0	29.8	26.5	24.5	28.7	25.4	25.6
6.380	55.1	3.2	51.9	35.8	32.6	19.3	34.0	30.8	21.1
				Average		21.4	21.7		

Table B38: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 0.775 mm; Measuring times range: 76.2 – 100.2 hours)

Time (hours)	0.0			82.2			100.2		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.1	3.0	8.1	3.0	0.0	8.1	3.0	0.0	8.1
1.000	12.4	2.4	10.0	2.4	0.0	10.0	2.4	0.0	10.0
1.500	16.1	2.5	13.6	2.5	0.0	13.6	2.5	0.0	13.6
2.000	22.7	2.5	20.2	2.5	0.0	20.2	2.5	0.0	20.2
2.500	25.6	0.9	24.7	1.0	0.1	24.6	1.0	0.1	24.6
3.000	27.5	2.0	25.5	2.0	0.0	25.5	2.0	0.0	25.5
3.500	32.3	2.5	29.8	4.2	1.7	28.1	4.0	1.5	28.3
4.000	33.0	2.0	31.0	8.8	6.8	24.2	8.8	6.8	24.2
4.500	37.9	2.0	35.9	12.0	10.0	25.9	12.0	10.0	25.9
5.000	44.0	1.8	42.2	16.5	14.7	27.5	16.1	14.3	27.9
5.500	49.5	2.0	47.5	20.5	18.5	29.0	19.9	17.9	29.6
6.000	54.6	3.4	51.2	23.0	19.6	31.6	24.0	20.6	30.6
6.095	54.7	3.4	51.3	24.9	21.5	29.8	25.6	22.2	29.1
6.190	54.3	3.5	50.8	25.9	22.4	28.4	24.6	21.1	29.7
6.285	54.3	3.3	51.0	27.9	24.6	26.4	27.0	23.7	27.3
6.380	55.1	3.2	51.9	35.0	31.8	20.1	34.4	31.2	20.7
				Average		21.9	22.1		

Table B39: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 0 – 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	10.2	7.2	1.1	9.5	6.5	1.8
1.000	12.8	2.4	10.4	11.3	8.9	1.5	11.2	8.8	1.6
1.500	17.2	2.5	14.7	16.7	14.2	0.5	16.5	14.0	0.7
2.000	23.2	2.5	20.7	22.7	20.2	0.5	22.4	19.9	0.8
2.500	25.5	0.9	24.6	24.8	23.9	0.7	24.4	23.5	1.1
3.000	32.3	2.0	30.3	31.0	29.0	1.3	28.9	26.9	3.4
3.500	36.2	2.5	33.7	32.2	29.7	4.0	31.5	29.0	4.7
4.000	39.3	2.0	37.3	34.9	32.9	4.4	33.3	31.3	6.0
4.500	43.7	2.0	41.7	37.8	35.8	5.9	35.6	33.6	8.1
5.000	44.4	1.8	42.6	40.4	38.6	4.0	38.3	36.5	6.1
5.500	46.4	2.0	44.4	41.4	39.4	5.0	40.9	38.9	5.5
6.000	51.2	3.4	47.8	42.5	39.1	8.7	43.0	39.6	8.2
6.095	52.3	3.4	48.9	43.7	40.3	8.6	43.3	39.9	9.0
6.190	54.5	3.5	51.0	44.2	40.7	10.3	42.7	39.2	11.8
6.285	56.0	3.3	52.7	45.0	41.7	11.0	43.7	40.4	12.3
6.380	56.9	3.2	53.7	47.2	44.0	9.7	47.1	43.9	9.8
			33.1		Average	4.5			5.3

Table B40: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 1 – 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	9.5	6.5	1.8	9.0	6.0	2.3
1.000	12.8	2.4	10.4	11.2	8.8	1.6	10.8	8.4	2.0
1.500	17.2	2.5	14.7	16.4	13.9	0.8	16.0	13.5	1.2
2.000	23.2	2.5	20.7	23.0	20.5	0.2	23.0	20.5	0.2
2.500	25.5	0.9	24.6	24.0	23.1	1.5	23.8	22.9	1.7
3.000	32.3	2.0	30.3	27.6	25.6	4.7	26.5	24.5	5.8
3.500	36.2	2.5	33.7	30.0	27.5	6.2	29.0	26.5	7.2
4.000	39.3	2.0	37.3	32.0	30.0	7.3	31.4	29.4	7.9
4.500	43.7	2.0	41.7	35.0	33.0	8.7	33.6	31.6	10.1
5.000	44.4	1.8	42.6	37.5	35.7	6.9	36.3	34.5	8.1
5.500	46.4	2.0	44.4	39.0	37.0	7.4	39.0	37.0	7.4
6.000	51.2	3.4	47.8	41.2	37.8	10.0	42.0	38.6	9.2
6.095	52.3	3.4	48.9	41.8	38.4	10.5	41.4	38.0	10.9
6.190	54.5	3.5	51.0	43.5	40.0	11.0	41.9	38.4	12.6
6.285	56.0	3.3	52.7	44.4	41.1	11.6	42.5	39.2	13.5
6.380	56.9	3.2	53.7	47.0	43.8	9.9	45.4	42.2	11.5
					Average	5.9			6.6

Table B41: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 2 – 6 hours)

Time (hours)	0.0			4.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	8.9	5.9	2.4	8.7	5.7	2.6
1.000	12.8	2.4	10.4	10.5	8.1	2.3	11.0	8.6	1.8
1.500	17.2	2.5	14.7	16.0	13.5	1.2	16.0	13.5	1.2
2.000	23.2	2.5	20.7	23.0	20.5	0.2	22.5	20.0	0.7
2.500	25.5	0.9	24.6	23.8	22.9	1.7	23.4	22.5	2.1
3.000	32.3	2.0	30.3	24.6	22.6	7.7	24.0	22.0	8.3
3.500	36.2	2.5	33.7	26.4	23.9	9.8	25.3	22.8	10.9
4.000	39.3	2.0	37.3	29.4	27.4	9.9	27.3	25.3	12.0
4.500	43.7	2.0	41.7	30.2	28.2	13.5	29.8	27.8	13.9
5.000	44.4	1.8	42.6	34.0	32.2	10.4	33.0	31.2	11.4
5.500	46.4	2.0	44.4	37.0	35.0	9.4	35.5	33.5	10.9
6.000	51.2	3.4	47.8	38.5	35.1	12.7	38.6	35.2	12.6
6.095	52.3	3.4	48.9	39.6	36.2	12.7	39.1	35.7	13.2
6.190	54.5	3.5	51.0	40.2	36.7	14.3	40.0	36.5	14.5
6.285	56.0	3.3	52.7	41.4	38.1	14.6	41.7	38.4	14.3
6.380	56.9	3.2	53.7	44.9	41.7	12.0	44.4	41.2	12.5
Average						7.9	8.4		

Table B42: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 6 – 20 hours)

Time (hours)	0.0			12.0			20.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	8.6	5.6	2.7	9.6	6.6	1.7
1.000	12.8	2.4	10.4	11.0	8.6	1.8	11.9	9.5	0.9
1.500	17.2	2.5	14.7	16.0	13.5	1.2	16.7	14.2	0.5
2.000	23.2	2.5	20.7	20.2	17.7	3.0	17.6	15.1	5.6
2.500	25.5	0.9	24.6	22.0	21.1	3.5	19.9	19.0	5.6
3.000	32.3	2.0	30.3	24.3	22.3	8.0	22.9	20.9	9.4
3.500	36.2	2.5	33.7	24.6	22.1	11.6	23.4	20.9	12.8
4.000	39.3	2.0	37.3	27.2	25.2	12.1	25.6	23.6	13.7
4.500	43.7	2.0	41.7	27.8	25.8	15.9	27.8	25.8	15.9
5.000	44.4	1.8	42.6	30.2	28.4	14.2	31.7	29.9	12.7
5.500	46.4	2.0	44.4	33.2	31.2	13.2	34.2	32.2	12.2
6.000	51.2	3.4	47.8	36.5	33.1	14.7	37.3	33.9	13.9
6.095	52.3	3.4	48.9	36.9	33.5	15.4	37.8	34.4	14.5
6.190	54.5	3.5	51.0	38.3	34.8	16.2	38.0	34.5	16.5
6.285	56.0	3.3	52.7	39.7	36.4	16.3	39.4	36.1	16.6
6.380	56.9	3.2	53.7	43.1	39.9	13.8	42.0	38.8	14.9
Average						9.6	9.8		

Table B43: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 20 – 48 hours)

Time (hours)	0.0			29.0			48.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	9.3	6.3	2.0	12.5	9.5	-1.2
1.000	12.8	2.4	10.4	11.9	9.5	0.9	12.5	10.1	0.3
1.500	17.2	2.5	14.7	16.4	13.9	0.8	15.7	13.2	1.5
2.000	23.2	2.5	20.7	16.9	14.4	6.3	16.3	13.8	6.9
2.500	25.5	0.9	24.6	19.0	18.1	6.5	17.3	16.4	8.2
3.000	32.3	2.0	30.3	21.3	19.3	11.0	19.4	17.4	12.9
3.500	36.2	2.5	33.7	22.2	19.7	14.0	20.9	18.4	15.3
4.000	39.3	2.0	37.3	24.6	22.6	14.7	23.7	21.7	15.6
4.500	43.7	2.0	41.7	27.8	25.8	15.9	26.4	24.4	17.3
5.000	44.4	1.8	42.6	30.3	28.5	14.1	29.0	27.2	15.4
5.500	46.4	2.0	44.4	33.5	31.5	12.9	31.9	29.9	14.5
6.000	51.2	3.4	47.8	36.2	32.8	15.0	35.0	31.6	16.2
6.095	52.3	3.4	48.9	37.3	33.9	15.0	35.7	32.3	16.6
6.190	54.5	3.5	51.0	38.0	34.5	16.5	37.0	33.5	17.5
6.285	56.0	3.3	52.7	39.4	36.1	16.6	38.2	34.9	17.8
6.380	56.9	3.2	53.7	41.0	37.8	15.9	40.9	37.7	16.0
				Average		10.5	11.2		

Table B44: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 48 – 69 hours)

Time (hours)	0.0			59.0			69.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	13.2	10.2	-1.9	12.5	9.5	-1.2
1.000	12.8	2.4	10.4	12.2	9.8	0.6	12.2	9.8	0.6
1.500	17.2	2.5	14.7	15.2	12.7	2.0	14.7	12.2	2.5
2.000	23.2	2.5	20.7	16.2	13.7	7.0	15.5	13.0	7.7
2.500	25.5	0.9	24.6	17.3	16.4	8.2	17.3	16.4	8.2
3.000	32.3	2.0	30.3	17.8	15.8	14.5	17.0	15.0	15.3
3.500	36.2	2.5	33.7	20.9	18.4	15.3	20.2	17.7	16.0
4.000	39.3	2.0	37.3	23.0	21.0	16.3	22.3	20.3	17.0
4.500	43.7	2.0	41.7	26.2	24.2	17.5	25.2	23.2	18.5
5.000	44.4	1.8	42.6	29.0	27.2	15.4	27.5	25.7	16.9
5.500	46.4	2.0	44.4	31.0	29.0	15.4	30.5	28.5	15.9
6.000	51.2	3.4	47.8	34.0	30.6	17.2	33.7	30.3	17.5
6.095	52.3	3.4	48.9	35.3	31.9	17.0	34.5	31.1	17.8
6.190	54.5	3.5	51.0	36.4	32.9	18.1	35.2	31.7	19.3
6.285	56.0	3.3	52.7	37.3	34.0	18.7	37.5	34.2	18.5
6.380	56.9	3.2	53.7	41.2	38.0	15.7	41.3	38.1	15.6
				Average		11.6	12.1		

Table B45: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 69 – 116 hours)

Time (hours)	0.0			107.0			116.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	11.9	8.9	-0.6	11.5	8.5	-0.2
1.000	12.8	2.4	10.4	11.0	8.6	1.8	12.3	9.9	0.5
1.500	17.2	2.5	14.7	12.5	10.0	4.7	11.7	9.2	5.5
2.000	23.2	2.5	20.7	15.2	12.7	8.0	14.7	12.2	8.5
2.500	25.5	0.9	24.6	16.9	16.0	8.6	16.5	15.6	9.0
3.000	32.3	2.0	30.3	17.4	15.4	14.9	17.2	15.2	15.1
3.500	36.2	2.5	33.7	20.2	17.7	16.0	20.0	17.5	16.2
4.000	39.3	2.0	37.3	21.9	19.9	17.4	21.7	19.7	17.6
4.500	43.7	2.0	41.7	25.2	23.2	18.5	25.0	23.0	18.7
5.000	44.4	1.8	42.6	27.6	25.8	16.8	27.7	25.9	16.7
5.500	46.4	2.0	44.4	30.3	28.3	16.1	30.0	28.0	16.4
6.000	51.2	3.4	47.8	33.8	30.4	17.4	33.5	30.1	17.7
6.095	52.3	3.4	48.9	34.3	30.9	18.0	34.0	30.6	18.3
6.190	54.5	3.5	51.0	35.2	31.7	19.3	35.0	31.5	19.5
6.285	56.0	3.3	52.7	36.6	33.3	19.4	35.8	32.5	20.2
6.380	56.9	3.2	53.7	41.0	37.8	15.9	41.3	38.1	15.6
Average						12.5	12.7		

Table B46: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 116 – 124 hours)

Time (hours)	0.0			121.0			124.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	11.2	8.2	0.1	11.3	8.3	0.0
1.000	12.8	2.4	10.4	12.3	9.9	0.5	12.9	10.5	-0.1
1.500	17.2	2.5	14.7	12.0	9.5	5.2	11.6	9.1	5.6
2.000	23.2	2.5	20.7	14.4	11.9	8.8	14.3	11.8	8.9
2.500	25.5	0.9	24.6	16.1	15.2	9.4	16.1	15.2	9.4
3.000	32.3	2.0	30.3	17.1	15.1	15.2	17.1	15.1	15.2
3.500	36.2	2.5	33.7	19.9	17.4	16.3	19.9	17.4	16.3
4.000	39.3	2.0	37.3	21.7	19.7	17.6	21.7	19.7	17.6
4.500	43.7	2.0	41.7	24.7	22.7	19.0	24.7	22.7	19.0
5.000	44.4	1.8	42.6	27.7	25.9	16.7	27.7	25.9	16.7
5.500	46.4	2.0	44.4	28.6	26.6	17.8	28.6	26.6	17.8
6.000	51.2	3.4	47.8	33.1	29.7	18.1	33.0	29.6	18.2
6.095	52.3	3.4	48.9	33.8	30.4	18.5	33.7	30.3	18.6
6.190	54.5	3.5	51.0	35.0	31.5	19.5	34.5	31.0	20.0
6.285	56.0	3.3	52.7	35.8	32.5	20.2	35.8	32.5	20.2
6.380	56.9	3.2	53.7	40.7	37.5	16.2	40.7	37.5	16.2
Average						12.9	12.9		

Table B47: Storage depletion data (Q_w : 6.9 litres/sec; D_{50} : 1.15 mm; Measuring times range: 124 – 138 hours)

Time (hours)	0.0			138.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.3	3.0	8.3	12.0	9.0	-0.7
1.000	12.8	2.4	10.4	12.9	10.5	-0.1
1.500	17.2	2.5	14.7	10.4	7.9	6.8
2.000	23.2	2.5	20.7	13.4	10.9	9.8
2.500	25.5	0.9	24.6	16.0	15.1	9.5
3.000	32.3	2.0	30.3	17.1	15.1	15.2
3.500	36.2	2.5	33.7	19.6	17.1	16.6
4.000	39.3	2.0	37.3	21.4	19.4	17.9
4.500	43.7	2.0	41.7	27.4	25.4	16.3
5.000	44.4	1.8	42.6	27.5	25.7	16.9
5.500	46.4	2.0	44.4	28.6	26.6	17.8
6.000	51.2	3.4	47.8	32.3	28.9	18.9
6.095	52.3	3.4	48.9	32.9	29.5	19.4
6.190	54.5	3.5	51.0	34.2	30.7	20.3
6.285	56.0	3.3	52.7	35.8	32.5	20.2
6.380	56.9	3.2	53.7	41.8	38.6	15.1
					Average	12.9

Table B48: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 0 – 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	9.5	6.5	0.9	9.5	6.5	0.9
1.000	16.2	2.4	13.8	15.2	12.8	1.0	14.8	12.4	1.4
1.500	18.7	2.5	16.2	17.4	14.9	1.3	17.0	14.5	1.7
2.000	27.4	2.5	24.9	25.5	23.0	1.9	24.7	22.2	2.7
2.500	29.7	0.9	28.8	28.5	27.6	1.2	28.2	27.3	1.5
3.000	30.0	2.0	28.0	29.6	27.6	0.4	29.0	27.0	1.0
3.500	35.5	2.5	33.0	28.9	26.4	6.6	27.8	25.3	7.7
4.000	41.9	2.0	39.9	31.9	29.9	10.0	30.5	28.5	11.4
4.500	45.3	2.0	43.3	35.8	33.8	9.5	33.5	31.5	11.8
5.000	50.0	1.8	48.2	39.0	37.2	11.0	36.9	35.1	13.1
5.500	55.2	2.0	53.2	41.0	39.0	14.2	40.5	38.5	14.7
6.000	56.4	3.4	53.0	42.2	38.8	14.2	42.2	38.8	14.2
6.095	56.4	3.4	53.0	44.8	41.4	11.6	41.3	37.9	15.1
6.190	55.9	3.5	52.4	44.8	41.3	11.1	41.5	38.0	14.4
6.285	56.0	3.3	52.7	44.5	41.2	11.5	43.2	39.9	12.8
6.380	55.5	3.2	52.3	46.5	43.3	9.0	44.8	41.6	10.7
					Average	6.8	7.9		

Table B49: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 1 – 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	9.2	6.2	1.2	9.0	6.0	1.4
1.000	16.2	2.4	13.8	14.6	12.2	1.6	14.4	12.0	1.8
1.500	18.7	2.5	16.2	16.8	14.3	1.9	16.8	14.3	1.9
2.000	27.4	2.5	24.9	22.7	20.2	4.7	21.4	18.9	6.0
2.500	29.7	0.9	28.8	26.3	25.4	3.4	24.1	23.2	5.6
3.000	30.0	2.0	28.0	27.8	25.8	2.2	27.1	25.1	2.9
3.500	35.5	2.5	33.0	29.0	26.5	6.5	28.2	25.7	7.3
4.000	41.9	2.0	39.9	30.8	28.8	11.1	30.2	28.2	11.7
4.500	45.3	2.0	43.3	32.8	30.8	12.5	32.8	30.8	12.5
5.000	50.0	1.8	48.2	36.7	34.9	13.3	36.0	34.2	14.0
5.500	55.2	2.0	53.2	37.2	35.2	18.0	36.4	34.4	18.8
6.000	56.4	3.4	53.0	40.2	36.8	16.2	38.5	35.1	17.9
6.095	56.4	3.4	53.0	40.5	37.1	15.9	39.2	35.8	17.2
6.190	55.9	3.5	52.4	41.5	38.0	14.4	38.3	34.8	17.6
6.285	56.0	3.3	52.7	43.2	39.9	12.8	39.4	36.1	16.6
6.380	55.5	3.2	52.3	44.5	41.3	11.0	43.7	40.5	11.8
Average						8.6	9.7		

Table B50: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 2 – 4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	9.0	6.0	1.4	8.8	5.8	1.6
1.000	16.2	2.4	13.8	14.0	11.6	2.2	14.0	11.6	2.2
1.500	18.7	2.5	16.2	18.0	15.5	0.7	18.0	15.5	0.7
2.000	27.4	2.5	24.9	20.5	18.0	6.9	19.5	17.0	7.9
2.500	29.7	0.9	28.8	22.1	21.2	7.6	21.0	20.1	8.7
3.000	30.0	2.0	28.0	24.4	22.4	5.6	23.4	21.4	6.6
3.500	35.5	2.5	33.0	27.3	24.8	8.2	25.5	23.0	10.0
4.000	41.9	2.0	39.9	28.7	26.7	13.2	28.2	26.2	13.7
4.500	45.3	2.0	43.3	31.1	29.1	14.2	29.3	27.3	16.0
5.000	50.0	1.8	48.2	34.2	32.4	15.8	32.7	30.9	17.3
5.500	55.2	2.0	53.2	36.0	34.0	19.2	36.0	34.0	19.2
6.000	56.4	3.4	53.0	38.8	35.4	17.6	40.0	36.6	16.4
6.095	56.4	3.4	53.0	39.7	36.3	16.7	40.5	37.1	15.9
6.190	55.9	3.5	52.4	40.4	36.9	15.5	40.4	36.9	15.5
6.285	56.0	3.3	52.7	41.9	38.6	14.1	40.2	36.9	15.8
6.380	55.5	3.2	52.3	44.8	41.6	10.7	43.2	40.0	12.3
Average						10.0	10.6		

Table B51: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 4 – 6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	9.0	6.0	1.4	8.8	5.8	1.6
1.000	16.2	2.4	13.8	14.2	11.8	2.0	14.0	11.6	2.2
1.500	18.7	2.5	16.2	18.0	15.5	0.7	18.0	15.5	0.7
2.000	27.4	2.5	24.9	18.3	15.8	9.1	17.8	15.3	9.6
2.500	29.7	0.9	28.8	20.3	19.4	9.4	19.6	18.7	10.1
3.000	30.0	2.0	28.0	23.0	21.0	7.0	22.5	20.5	7.5
3.500	35.5	2.5	33.0	24.9	22.4	10.6	24.8	22.3	10.7
4.000	41.9	2.0	39.9	27.0	25.0	14.9	25.9	23.9	16.0
4.500	45.3	2.0	43.3	28.5	26.5	16.8	28.4	26.4	16.9
5.000	50.0	1.8	48.2	32.2	30.4	17.8	32.1	30.3	17.9
5.500	55.2	2.0	53.2	36.0	34.0	19.2	35.8	33.8	19.4
6.000	56.4	3.4	53.0	36.4	33.0	20.0	37.0	33.6	19.4
6.095	56.4	3.4	53.0	37.8	34.4	18.6	37.8	34.4	18.6
6.190	55.9	3.5	52.4	38.5	35.0	17.4	38.3	34.8	17.6
6.285	56.0	3.3	52.7	39.9	36.6	16.1	39.9	36.6	16.1
6.380	55.5	3.2	52.3	43.2	40.0	12.3	43.0	39.8	12.5
				Average		11.4	11.6		

Table B52: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 6 – 8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	8.8	5.8	1.6	8.4	5.4	2.0
1.000	16.2	2.4	13.8	14.2	11.8	2.0	14.0	11.6	2.2
1.500	18.7	2.5	16.2	18.0	15.5	0.7	18.0	15.5	0.7
2.000	27.4	2.5	24.9	17.0	14.5	10.4	16.4	13.9	11.0
2.500	29.7	0.9	28.8	18.9	18.0	10.8	18.4	17.5	11.3
3.000	30.0	2.0	28.0	21.8	19.8	8.2	21.5	19.5	8.5
3.500	35.5	2.5	33.0	24.0	21.5	11.5	23.0	20.5	12.5
4.000	41.9	2.0	39.9	25.7	23.7	16.2	25.5	23.5	16.4
4.500	45.3	2.0	43.3	27.4	25.4	17.9	28.1	26.1	17.2
5.000	50.0	1.8	48.2	31.7	29.9	18.3	31.0	29.2	19.0
5.500	55.2	2.0	53.2	34.2	32.2	21.0	32.7	30.7	22.5
6.000	56.4	3.4	53.0	37.3	33.9	19.1	36.4	33.0	20.0
6.095	56.4	3.4	53.0	37.6	34.2	18.8	37.0	33.6	19.4
6.190	55.9	3.5	52.4	38.0	34.5	17.9	37.7	34.2	18.2
6.285	56.0	3.3	52.7	39.7	36.4	16.3	38.7	35.4	17.3
6.380	55.5	3.2	52.3	43.0	39.8	12.5	42.4	39.2	13.1
				Average		12.0	12.4		

Table B53: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 8 – 12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	9.0	6.0	1.4	10.4	7.4	0.0
1.000	16.2	2.4	13.8	13.9	11.5	2.3	13.9	11.5	2.3
1.500	18.7	2.5	16.2	18.0	15.5	0.7	17.4	14.9	1.3
2.000	27.4	2.5	24.9	15.5	13.0	11.9	15.2	12.7	12.2
2.500	29.7	0.9	28.8	18.0	17.1	11.7	17.4	16.5	12.3
3.000	30.0	2.0	28.0	21.0	19.0	9.0	20.4	18.4	9.6
3.500	35.5	2.5	33.0	23.0	20.5	12.5	22.9	20.4	12.6
4.000	41.9	2.0	39.9	24.9	22.9	17.0	24.5	22.5	17.4
4.500	45.3	2.0	43.3	27.4	25.4	17.9	27.4	25.4	17.9
5.000	50.0	1.8	48.2	29.6	27.8	20.4	29.5	27.7	20.5
5.500	55.2	2.0	53.2	33.5	31.5	21.7	31.7	29.7	23.5
6.000	56.4	3.4	53.0	35.5	32.1	20.9	35.7	32.3	20.7
6.095	56.4	3.4	53.0	36.0	32.6	20.4	36.2	32.8	20.2
6.190	55.9	3.5	52.4	37.4	33.9	18.5	37.3	33.8	18.6
6.285	56.0	3.3	52.7	38.5	35.2	17.5	39.3	36.0	16.7
6.380	55.5	3.2	52.3	42.3	39.1	13.2	42.7	39.5	12.8
				Average		12.8			12.9

Table B54: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 12 – 24 hours)

Time (hours)	0.0			15.0			24.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	11.9	8.9	-1.5	11.4	8.4	-1.0
1.000	16.2	2.4	13.8	13.7	11.3	2.5	13.5	11.1	2.7
1.500	18.7	2.5	16.2	17.2	14.7	1.5	16.8	14.3	1.9
2.000	27.4	2.5	24.9	15.2	12.7	12.2	15.2	12.7	12.2
2.500	29.7	0.9	28.8	17.0	16.1	12.7	17.0	16.1	12.7
3.000	30.0	2.0	28.0	19.9	17.9	10.1	19.6	17.6	10.4
3.500	35.5	2.5	33.0	21.9	19.4	13.6	21.4	18.9	14.1
4.000	41.9	2.0	39.9	23.9	21.9	18.0	23.3	21.3	18.6
4.500	45.3	2.0	43.3	26.8	24.8	18.5	25.8	23.8	19.5
5.000	50.0	1.8	48.2	29.4	27.6	20.6	28.6	26.8	21.4
5.500	55.2	2.0	53.2	32.0	30.0	23.2	31.5	29.5	23.7
6.000	56.4	3.4	53.0	35.7	32.3	20.7	35.0	31.6	21.4
6.095	56.4	3.4	53.0	36.0	32.6	20.4	35.2	31.8	21.2
6.190	55.9	3.5	52.4	37.3	33.8	18.6	36.2	32.7	19.7
6.285	56.0	3.3	52.7	38.5	35.2	17.5	37.3	34.0	18.7
6.380	55.5	3.2	52.3	42.0	38.8	13.5	41.8	38.6	13.7
				Average		13.1			13.6

Table B55: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 24 – 39 hours)

Time (hours)	0.0			34.0			39.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	11.2	8.2	-0.8	10.8	7.8	-0.4
1.000	16.2	2.4	13.8	12.9	10.5	3.3	12.3	9.9	3.9
1.500	18.7	2.5	16.2	15.2	12.7	3.5	14.3	11.8	4.4
2.000	27.4	2.5	24.9	14.5	12.0	12.9	13.8	11.3	13.6
2.500	29.7	0.9	28.8	16.2	15.3	13.5	16.5	15.6	13.2
3.000	30.0	2.0	28.0	18.5	16.5	11.5	19.0	17.0	11.0
3.500	35.5	2.5	33.0	20.3	17.8	15.2	19.9	17.4	15.6
4.000	41.9	2.0	39.9	22.0	20.0	19.9	22.6	20.6	19.3
4.500	45.3	2.0	43.3	25.5	23.5	19.8	24.2	22.2	21.1
5.000	50.0	1.8	48.2	28.3	26.5	21.7	28.0	26.2	22.0
5.500	55.2	2.0	53.2	31.0	29.0	24.2	31.0	29.0	24.2
6.000	56.4	3.4	53.0	33.7	30.3	22.7	33.5	30.1	22.9
6.095	56.4	3.4	53.0	34.4	31.0	22.0	34.9	31.5	21.5
6.190	55.9	3.5	52.4	34.2	30.7	21.7	35.0	31.5	20.9
6.285	56.0	3.3	52.7	36.9	33.6	19.1	36.7	33.4	19.3
6.380	55.5	3.2	52.3	40.3	37.1	15.2	40.8	37.6	14.7
				Average		14.4	14.5		

Table B56: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 39 – 57 hours)

Time (hours)	0.0			49.0			57.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	11.3	8.3	-0.9	10.9	7.9	-0.5
1.000	16.2	2.4	13.8	12.3	9.9	3.9	11.5	9.1	4.7
1.500	18.7	2.5	16.2	13.7	11.2	5.0	13.0	10.5	5.7
2.000	27.4	2.5	24.9	13.7	11.2	13.7	13.0	10.5	14.4
2.500	29.7	0.9	28.8	16.0	15.1	13.7	15.5	14.6	14.2
3.000	30.0	2.0	28.0	18.0	16.0	12.0	17.5	15.5	12.5
3.500	35.5	2.5	33.0	19.9	17.4	15.6	19.7	17.2	15.8
4.000	41.9	2.0	39.9	22.5	20.5	19.4	22.0	20.0	19.9
4.500	45.3	2.0	43.3	24.8	22.8	20.5	24.2	22.2	21.1
5.000	50.0	1.8	48.2	28.1	26.3	21.9	27.5	25.7	22.5
5.500	55.2	2.0	53.2	31.0	29.0	24.2	30.3	28.3	24.9
6.000	56.4	3.4	53.0	33.0	29.6	23.4	33.4	30.0	23.0
6.095	56.4	3.4	53.0	34.0	30.6	22.4	34.5	31.1	21.9
6.190	55.9	3.5	52.4	35.0	31.5	20.9	36.3	32.8	19.6
6.285	56.0	3.3	52.7	36.0	32.7	20.0	37.2	33.9	18.8
6.380	55.5	3.2	52.3	40.5	37.3	15.0	40.3	37.1	15.2
				Average		14.7	14.9		

Table B57: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 57 – 87 hours)

Time (hours)	0.0			74.0			87.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	10.5	7.5	-0.1	9.3	6.3	1.1
1.000	16.2	2.4	13.8	10.4	8.0	5.8	10.0	7.6	6.2
1.500	18.7	2.5	16.2	12.3	9.8	6.4	11.9	9.4	6.8
2.000	27.4	2.5	24.9	11.6	9.1	15.8	12.3	9.8	15.1
2.500	29.7	0.9	28.8	15.3	14.4	14.4	15.1	14.2	14.6
3.000	30.0	2.0	28.0	17.3	15.3	12.7	17.3	15.3	12.7
3.500	35.5	2.5	33.0	19.2	16.7	16.3	18.9	16.4	16.6
4.000	41.9	2.0	39.9	21.9	19.9	20.0	20.9	18.9	21.0
4.500	45.3	2.0	43.3	24.2	22.2	21.1	23.8	21.8	21.5
5.000	50.0	1.8	48.2	27.2	25.4	22.8	26.3	24.5	23.7
5.500	55.2	2.0	53.2	29.4	27.4	25.8	28.3	26.3	26.9
6.000	56.4	3.4	53.0	33.0	29.6	23.4	32.9	29.5	23.5
6.095	56.4	3.4	53.0	33.3	29.9	23.1	33.2	29.8	23.2
6.190	55.9	3.5	52.4	35.0	31.5	20.9	34.5	31.0	21.4
6.285	56.0	3.3	52.7	34.9	31.6	21.1	35.0	31.7	21.0
6.380	55.5	3.2	52.3	39.6	36.4	15.9	40.8	37.6	14.7
Average						15.6	15.9		

Table B58: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 87 – 107 hours)

Time (hours)	0.0			98.0			107.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	3.0	0.0	7.4	3.0	0.0	7.4
1.000	16.2	2.4	13.8	10.4	8.0	5.8	9.5	7.1	6.7
1.500	18.7	2.5	16.2	11.8	9.3	6.9	11.7	9.2	7.0
2.000	27.4	2.5	24.9	12.3	9.8	15.1	12.0	9.5	15.4
2.500	29.7	0.9	28.8	15.0	14.1	14.7	14.3	13.4	15.4
3.000	30.0	2.0	28.0	16.9	14.9	13.1	16.9	14.9	13.1
3.500	35.5	2.5	33.0	18.7	16.2	16.8	18.7	16.2	16.8
4.000	41.9	2.0	39.9	20.8	18.8	21.1	20.5	18.5	21.4
4.500	45.3	2.0	43.3	23.3	21.3	22.0	23.5	21.5	21.8
5.000	50.0	1.8	48.2	26.0	24.2	24.0	25.5	23.7	24.5
5.500	55.2	2.0	53.2	28.3	26.3	26.9	28.7	26.7	26.5
6.000	56.4	3.4	53.0	32.4	29.0	24.0	32.4	29.0	24.0
6.095	56.4	3.4	53.0	32.9	29.5	23.5	32.5	29.1	23.9
6.190	55.9	3.5	52.4	34.0	30.5	21.9	33.4	29.9	22.5
6.285	56.0	3.3	52.7	35.0	31.7	21.0	33.8	30.5	22.2
6.380	55.5	3.2	52.3	39.9	36.7	15.6	40.0	36.8	15.5
Average						16.5	16.7		

Table B59: Storage depletion data (Q_w : 7.5 litres/sec; D_{50} : 1.15 mm; Measuring times range: 107 – 131 hours)

Time (hours)	0.0			121.0			131.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	10.4	3.0	7.4	3.0	0.0	7.4	3.0	0.0	7.4
1.000	16.2	2.4	13.8	8.8	6.4	7.4	9.2	6.8	7.0
1.500	18.7	2.5	16.2	10.9	8.4	7.8	10.5	8.0	8.2
2.000	27.4	2.5	24.9	11.5	9.0	15.9	11.0	8.5	16.4
2.500	29.7	0.9	28.8	13.7	12.8	16.0	14.0	13.1	15.7
3.000	30.0	2.0	28.0	16.4	14.4	13.6	16.0	14.0	14.0
3.500	35.5	2.5	33.0	17.6	15.1	17.9	17.8	15.3	17.7
4.000	41.9	2.0	39.9	20.0	18.0	21.9	19.4	17.4	22.5
4.500	45.3	2.0	43.3	22.9	20.9	22.4	22.5	20.5	22.8
5.000	50.0	1.8	48.2	25.2	23.4	24.8	24.5	22.7	25.5
5.500	55.2	2.0	53.2	28.0	26.0	27.2	28.0	26.0	27.2
6.000	56.4	3.4	53.0	32.2	28.8	24.2	32.0	28.6	24.4
6.095	56.4	3.4	53.0	32.4	29.0	24.0	32.0	28.6	24.4
6.190	55.9	3.5	52.4	33.8	30.3	22.1	32.9	29.4	23.0
6.285	56.0	3.3	52.7	35.5	32.2	20.5	35.3	32.0	20.7
6.380	55.5	3.2	52.3	41.5	38.3	14.0	39.6	36.4	15.9
			35.3		Average	16.9			17.2

Table B60: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 0 – 1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	10.8	7.8	0.7	10.3	7.3	1.2
1.000	14.2	2.4	11.8	13.9	11.5	0.3	13.4	11.0	0.8
1.500	16.4	2.5	13.9	15.9	13.4	0.5	15.9	13.4	0.5
2.000	20.5	2.5	18.0	20.2	17.7	0.3	20.0	17.5	0.5
2.500	22.6	0.9	21.7	20.2	19.3	2.4	20.2	19.3	2.4
3.000	31.9	2.0	29.9	24.4	22.4	7.5	20.5	18.5	11.4
3.500	36.6	2.5	34.1	27.3	24.8	9.3	24.5	22.0	12.1
4.000	39.0	2.0	37.0	32.7	30.7	6.3	28.2	26.2	10.8
4.500	43.8	2.0	41.8	35.9	33.9	7.9	31.8	29.8	12.0
5.000	51.0	1.8	49.2	37.3	35.5	13.7	34.2	32.4	16.8
5.500	52.5	2.0	50.5	38.0	36.0	14.5	36.5	34.5	16.0
6.000	57.3	3.4	53.9	42.8	39.4	14.5	41.2	37.8	16.1
6.095	58.2	3.4	54.8	38.9	35.5	19.3	41.9	38.5	16.3
6.190	58.3	3.5	54.8	39.8	36.3	18.5	38.0	34.5	20.3
6.285	58.4	3.3	55.1	39.0	35.7	19.4	40.2	36.9	18.2
6.380	58.4	3.2	55.2	39.5	36.3	18.9	44.0	40.8	14.4
			34.7		Average	9.1			10.0

Table B61: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 1 – 2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	10.0	7.0	1.5	10.0	7.0	1.5
1.000	14.2	2.4	11.8	12.3	9.9	1.9	11.5	9.1	2.7
1.500	16.4	2.5	13.9	15.3	12.8	1.1	15.2	12.7	1.2
2.000	20.5	2.5	18.0	18.6	16.1	1.9	18.2	15.7	2.3
2.500	22.6	0.9	21.7	20.5	19.6	2.1	20.5	19.6	2.1
3.000	31.9	2.0	29.9	19.0	17.0	12.9	20.3	18.3	11.6
3.500	36.6	2.5	34.1	22.8	20.3	13.8	22.1	19.6	14.5
4.000	39.0	2.0	37.0	26.3	24.3	12.7	24.9	22.9	14.1
4.500	43.8	2.0	41.8	30.2	28.2	13.6	29.0	27.0	14.8
5.000	51.0	1.8	49.2	33.9	32.1	17.1	31.8	30.0	19.2
5.500	52.5	2.0	50.5	36.2	34.2	16.3	34.6	32.6	17.9
6.000	57.3	3.4	53.9	38.5	35.1	18.8	38.0	34.6	19.3
6.095	58.2	3.4	54.8	40.9	37.5	17.3	38.6	35.2	19.6
6.190	58.3	3.5	54.8	40.8	37.3	17.5	38.6	35.1	19.7
6.285	58.4	3.3	55.1	39.5	36.2	18.9	38.9	35.6	19.5
6.380	58.4	3.2	55.2	42.8	39.6	15.6	42.5	39.3	15.9
				Average		10.8	11.5		

Table B62: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 2 – 4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	10.8	7.8	0.7	10.7	7.7	0.8
1.000	14.2	2.4	11.8	11.0	8.6	3.2	10.4	8.0	3.8
1.500	16.4	2.5	13.9	15.2	12.7	1.2	14.7	12.2	1.7
2.000	20.5	2.5	18.0	16.4	13.9	4.1	13.5	11.0	7.0
2.500	22.6	0.9	21.7	19.7	18.8	2.9	18.5	17.6	4.1
3.000	31.9	2.0	29.9	19.8	17.8	12.1	19.0	17.0	12.9
3.500	36.6	2.5	34.1	21.8	19.3	14.8	21.3	18.8	15.3
4.000	39.0	2.0	37.0	24.9	22.9	14.1	23.0	21.0	16.0
4.500	43.8	2.0	41.8	27.2	25.2	16.6	27.0	25.0	16.8
5.000	51.0	1.8	49.2	29.7	27.9	21.3	29.3	27.5	21.7
5.500	52.5	2.0	50.5	32.8	30.8	19.7	30.0	28.0	22.5
6.000	57.3	3.4	53.9	35.5	32.1	21.8	34.0	30.6	23.3
6.095	58.2	3.4	54.8	36.4	33.0	21.8	34.9	31.5	23.3
6.190	58.3	3.5	54.8	34.9	31.4	23.4	35.8	32.3	22.5
6.285	58.4	3.3	55.1	37.5	34.2	20.9	36.7	33.4	21.7
6.380	58.4	3.2	55.2	41.8	38.6	16.6	41.0	37.8	17.4
				Average		12.7	13.6		

Table B63: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 4 – 6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	10.5	7.5	1.0	10.3	7.3	1.2
1.000	14.2	2.4	11.8	9.9	7.5	4.3	9.9	7.5	4.3
1.500	16.4	2.5	13.9	14.3	11.8	2.1	14.0	11.5	2.4
2.000	20.5	2.5	18.0	14.3	11.8	6.2	14.0	11.5	6.5
2.500	22.6	0.9	21.7	16.4	15.5	6.2	16.2	15.3	6.4
3.000	31.9	2.0	29.9	18.0	16.0	13.9	17.3	15.3	14.6
3.500	36.6	2.5	34.1	20.0	17.5	16.6	19.9	17.4	16.7
4.000	39.0	2.0	37.0	22.6	20.6	16.4	22.0	20.0	17.0
4.500	43.8	2.0	41.8	24.9	22.9	18.9	25.5	23.5	18.3
5.000	51.0	1.8	49.2	28.9	27.1	22.1	27.8	26.0	23.2
5.500	52.5	2.0	50.5	32.2	30.2	20.3	32.0	30.0	20.5
6.000	57.3	3.4	53.9	34.8	31.4	22.5	33.8	30.4	23.5
6.095	58.2	3.4	54.8	34.7	31.3	23.5	33.5	30.1	24.7
6.190	58.3	3.5	54.8	35.0	31.5	23.3	35.0	31.5	23.3
6.285	58.4	3.3	55.1	36.7	33.4	21.7	35.9	32.6	22.5
6.380	58.4	3.2	55.2	40.3	37.1	18.1	37.3	34.1	21.1
Average						13.9	14.5		

Table B64: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 6 – 8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	9.8	6.8	1.7	9.6	6.6	1.9
1.000	14.2	2.4	11.8	9.9	7.5	4.3	9.7	7.3	4.5
1.500	16.4	2.5	13.9	13.6	11.1	2.8	13.3	10.8	3.1
2.000	20.5	2.5	18.0	13.9	11.4	6.6	14.3	11.8	6.2
2.500	22.6	0.9	21.7	15.4	14.5	7.2	15.3	14.4	7.3
3.000	31.9	2.0	29.9	17.3	15.3	14.6	17.0	15.0	14.9
3.500	36.6	2.5	34.1	19.0	16.5	17.6	19.0	16.5	17.6
4.000	39.0	2.0	37.0	22.0	20.0	17.0	20.9	18.9	18.1
4.500	43.8	2.0	41.8	23.5	21.5	20.3	24.4	22.4	19.4
5.000	51.0	1.8	49.2	27.2	25.4	23.8	27.0	25.2	24.0
5.500	52.5	2.0	50.5	29.9	27.9	22.6	29.2	27.2	23.3
6.000	57.3	3.4	53.9	33.8	30.4	23.5	31.5	28.1	25.8
6.095	58.2	3.4	54.8	33.5	30.1	24.7	32.7	29.3	25.5
6.190	58.3	3.5	54.8	33.6	30.1	24.7	33.3	29.8	25.0
6.285	58.4	3.3	55.1	34.4	31.1	24.0	34.8	31.5	23.6
6.380	58.4	3.2	55.2	38.5	35.3	19.9	38.0	34.8	20.4
Average						15.0	15.3		

Table B65: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 8 – 12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	9.6	7.2	4.6	8.7	6.3	5.5
1.500	16.4	2.5	13.9	13.1	10.6	3.3	13.0	10.5	3.4
2.000	20.5	2.5	18.0	14.1	11.6	6.4	13.4	10.9	7.1
2.500	22.6	0.9	21.7	15.3	14.4	7.3	14.7	13.8	7.9
3.000	31.9	2.0	29.9	17.0	15.0	14.9	16.7	14.7	15.2
3.500	36.6	2.5	34.1	19.1	16.6	17.5	18.5	16.0	18.1
4.000	39.0	2.0	37.0	20.5	18.5	18.5	20.5	18.5	18.5
4.500	43.8	2.0	41.8	24.0	22.0	19.8	23.7	21.7	20.1
5.000	51.0	1.8	49.2	26.9	25.1	24.1	26.2	24.4	24.8
5.500	52.5	2.0	50.5	29.2	27.2	23.3	27.5	25.5	25.0
6.000	57.3	3.4	53.9	33.0	29.6	24.3	30.9	27.5	26.4
6.095	58.2	3.4	54.8	33.0	29.6	25.2	32.0	28.6	26.2
6.190	58.3	3.5	54.8	33.0	29.5	25.3	32.6	29.1	25.7
6.285	58.4	3.3	55.1	33.6	30.3	24.8	34.0	30.7	24.4
6.380	58.4	3.2	55.2	38.4	35.2	20.0	36.9	33.7	21.5
Average						15.8	16.4		

Table B66: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 12 – 23 hours)

Time (hours)	0.0			14.0			23.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	8.0	5.6	6.2	6.6	4.2	7.6
1.500	16.4	2.5	13.9	12.0	9.5	4.4	10.0	7.5	6.4
2.000	20.5	2.5	18.0	12.9	10.4	7.6	11.4	8.9	9.1
2.500	22.6	0.9	21.7	14.7	13.8	7.9	13.0	12.1	9.6
3.000	31.9	2.0	29.9	16.0	14.0	15.9	15.5	13.5	16.4
3.500	36.6	2.5	34.1	18.0	15.5	18.6	17.0	14.5	19.6
4.000	39.0	2.0	37.0	20.3	18.3	18.7	19.0	17.0	20.0
4.500	43.8	2.0	41.8	23.4	21.4	20.4	22.8	20.8	21.0
5.000	51.0	1.8	49.2	26.3	24.5	24.7	24.0	22.2	27.0
5.500	52.5	2.0	50.5	28.5	26.5	24.0	26.5	24.5	26.0
6.000	57.3	3.4	53.9	32.0	28.6	25.3	29.8	26.4	27.5
6.095	58.2	3.4	54.8	32.2	28.8	26.0	30.5	27.1	27.7
6.190	58.3	3.5	54.8	33.3	29.8	25.0	32.5	29.0	25.8
6.285	58.4	3.3	55.1	35.5	32.2	22.9	33.7	30.4	24.7
6.380	58.4	3.2	55.2	37.9	34.7	20.5	37.8	34.6	20.6
Average						16.3	17.5		

Table B67: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 23 – 32 hours)

Time (hours)	0.0			26.0			32.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	10.0	7.5	6.4	9.3	6.8	7.1
2.000	20.5	2.5	18.0	11.4	8.9	9.1	11.4	8.9	9.1
2.500	22.6	0.9	21.7	12.3	11.4	10.3	11.5	10.6	11.1
3.000	31.9	2.0	29.9	14.9	12.9	17.0	14.0	12.0	17.9
3.500	36.6	2.5	34.1	17.0	14.5	19.6	16.1	13.6	20.5
4.000	39.0	2.0	37.0	19.0	17.0	20.0	19.0	17.0	20.0
4.500	43.8	2.0	41.8	22.8	20.8	21.0	21.8	19.8	22.0
5.000	51.0	1.8	49.2	23.3	21.5	27.7	22.8	21.0	28.2
5.500	52.5	2.0	50.5	26.5	24.5	26.0	26.0	24.0	26.5
6.000	57.3	3.4	53.9	27.8	24.4	29.5	29.9	26.5	27.4
6.095	58.2	3.4	54.8	28.9	25.5	29.3	30.0	26.6	28.2
6.190	58.3	3.5	54.8	30.2	26.7	28.1	30.7	27.2	27.6
6.285	58.4	3.3	55.1	31.7	28.4	26.7	32.8	29.5	25.6
6.380	58.4	3.2	55.2	37.3	34.1	21.1	36.9	33.7	21.5
Average						18.4	18.4		

Table B68: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 32 – 49 hours)

Time (hours)	0.0			37.0			49.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	9.2	6.7	7.2	2.5	0.0	13.9
2.000	20.5	2.5	18.0	10.4	7.9	10.1	10.4	7.9	10.1
2.500	22.6	0.9	21.7	11.4	10.5	11.2	11.4	10.5	11.2
3.000	31.9	2.0	29.9	14.0	12.0	17.9	13.0	11.0	18.9
3.500	36.6	2.5	34.1	16.1	13.6	20.5	15.7	13.2	20.9
4.000	39.0	2.0	37.0	18.9	16.9	20.1	17.9	15.9	21.1
4.500	43.8	2.0	41.8	20.3	18.3	23.5	20.2	18.2	23.6
5.000	51.0	1.8	49.2	22.8	21.0	28.2	22.9	21.1	28.1
5.500	52.5	2.0	50.5	25.7	23.7	26.8	25.7	23.7	26.8
6.000	57.3	3.4	53.9	29.4	26.0	27.9	27.8	24.4	29.5
6.095	58.2	3.4	54.8	30.3	26.9	27.9	29.0	25.6	29.2
6.190	58.3	3.5	54.8	31.5	28.0	26.8	29.5	26.0	28.8
6.285	58.4	3.3	55.1	32.5	29.2	25.9	31.9	28.6	26.5
6.380	58.4	3.2	55.2	37.5	34.3	20.9	37.8	34.6	20.6
Average						18.5	19.4		

Table B69: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 49 – 61 hours)

Time (hours)	0.0			55.0			61.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	2.5	0.0	13.9	2.5	0.0	13.9
2.000	20.5	2.5	18.0	9.9	7.4	10.6	9.6	7.1	10.9
2.500	22.6	0.9	21.7	11.4	10.5	11.2	11.0	10.1	11.6
3.000	31.9	2.0	29.9	13.0	11.0	18.9	12.8	10.8	19.1
3.500	36.6	2.5	34.1	15.1	12.6	21.5	15.0	12.5	21.6
4.000	39.0	2.0	37.0	17.5	15.5	21.5	17.3	15.3	21.7
4.500	43.8	2.0	41.8	19.9	17.9	23.9	19.3	17.3	24.5
5.000	51.0	1.8	49.2	22.5	20.7	28.5	21.2	19.4	29.8
5.500	52.5	2.0	50.5	25.5	23.5	27.0	24.5	22.5	28.0
6.000	57.3	3.4	53.9	28.9	25.5	28.4	27.6	24.2	29.7
6.095	58.2	3.4	54.8	29.5	26.1	28.7	28.1	24.7	30.1
6.190	58.3	3.5	54.8	30.2	26.7	28.1	29.0	25.5	29.3
6.285	58.4	3.3	55.1	31.9	28.6	26.5	30.9	27.6	27.5
6.380	58.4	3.2	55.2	36.5	33.3	21.9	37.3	34.1	21.1
Average						19.5	19.9		

Table B70: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 61 – 79 hours)

Time (hours)	0.0			73.0			79.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	2.5	0.0	13.9	2.5	0.0	13.9
2.000	20.5	2.5	18.0	9.8	7.3	10.7	8.2	5.7	12.3
2.500	22.6	0.9	21.7	11.4	10.5	11.2	11.0	10.1	11.6
3.000	31.9	2.0	29.9	13.2	11.2	18.7	13.0	11.0	18.9
3.500	36.6	2.5	34.1	15.9	13.4	20.7	15.3	12.8	21.3
4.000	39.0	2.0	37.0	17.5	15.5	21.5	17.5	15.5	21.5
4.500	43.8	2.0	41.8	18.9	16.9	24.9	20.0	18.0	23.8
5.000	51.0	1.8	49.2	21.9	20.1	29.1	21.7	19.9	29.3
5.500	52.5	2.0	50.5	24.2	22.2	28.3	23.4	21.4	29.1
6.000	57.3	3.4	53.9	27.5	24.1	29.8	26.9	23.5	30.4
6.095	58.2	3.4	54.8	28.0	24.6	30.2	27.3	23.9	30.9
6.190	58.3	3.5	54.8	28.7	25.2	29.6	28.0	24.5	30.3
6.285	58.4	3.3	55.1	30.3	27.0	28.1	30.4	27.1	28.0
6.380	58.4	3.2	55.2	37.0	33.8	21.4	37.5	34.3	20.9
Average						19.9	20.1		

Table B71: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 79 – 96 hours)

Time (hours)	0.0			85.0			96.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	2.5	0.0	13.9	2.5	0.0	13.9
2.000	20.5	2.5	18.0	6.3	3.8	14.2	3.4	0.9	17.1
2.500	22.6	0.9	21.7	11.0	10.1	11.6	10.7	9.8	11.9
3.000	31.9	2.0	29.9	12.3	10.3	19.6	12.3	10.3	19.6
3.500	36.6	2.5	34.1	15.0	12.5	21.6	15.0	12.5	21.6
4.000	39.0	2.0	37.0	17.3	15.3	21.7	16.5	14.5	22.5
4.500	43.8	2.0	41.8	19.3	17.3	24.5	18.5	16.5	25.3
5.000	51.0	1.8	49.2	22.3	20.5	28.7	21.6	19.8	29.4
5.500	52.5	2.0	50.5	25.3	23.3	27.2	24.0	22.0	28.5
6.000	57.3	3.4	53.9	28.5	25.1	28.8	27.7	24.3	29.6
6.095	58.2	3.4	54.8	27.8	24.4	30.4	28.2	24.8	30.0
6.190	58.3	3.5	54.8	28.0	24.5	30.3	29.3	25.8	29.0
6.285	58.4	3.3	55.1	29.8	26.5	28.6	31.5	28.2	26.9
6.380	58.4	3.2	55.2	36.0	32.8	22.4	37.3	34.1	21.1
				Average		20.2	20.4		

Table B72: Storage depletion data (Q_w : 8.4 litres/sec; D_{50} : 1.15 mm; Measuring times range: 96 – 100 hours)

Time (hours)	0.0			100.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	11.5	3.0	8.5	3.0	0.0	8.5
1.000	14.2	2.4	11.8	2.4	0.0	11.8
1.500	16.4	2.5	13.9	2.5	0.0	13.9
2.000	20.5	2.5	18.0	3.1	0.6	17.4
2.500	22.6	0.9	21.7	10.7	9.8	11.9
3.000	31.9	2.0	29.9	11.5	9.5	20.4
3.500	36.6	2.5	34.1	14.4	11.9	22.2
4.000	39.0	2.0	37.0	16.7	14.7	22.3
4.500	43.8	2.0	41.8	19.8	17.8	24.0
5.000	51.0	1.8	49.2	21.0	19.2	30.0
5.500	52.5	2.0	50.5	23.0	21.0	29.5
6.000	57.3	3.4	53.9	27.2	23.8	30.1
6.095	58.2	3.4	54.8	28.0	24.6	30.2
6.190	58.3	3.5	54.8	28.5	25.0	29.8
6.285	58.4	3.3	55.1	30.5	27.2	27.9
6.380	58.4	3.2	55.2	37.3	34.1	21.1
				Average		20.6

APPENDIX C: Active storage dataTable C1: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	11.3	5.4	0.9	9.0	3.1	3.2
1.000	12.5	4.5	8.0	13.1	8.6	-0.6	11.1	6.6	1.4
1.500	15.2	4.7	10.5	15.1	10.4	0.1	15.5	10.8	-0.3
2.000	20.5	5.0	15.5	18.1	13.1	2.4	16.0	11.0	4.5
2.500	24.8	3.5	21.3	22.4	18.9	2.4	19.7	16.2	5.1
3.000	28.1	4.2	23.9	25.0	20.8	3.1	22.1	17.9	6.0
3.500	32.0	5.2	26.8	25.5	20.3	6.5	25.0	19.8	7.0
4.000	37.5	4.0	33.5	27.9	23.9	9.6	28.6	24.6	8.9
4.500	42.2	4.1	38.1	35.7	31.6	6.5	32.0	27.9	10.2
5.000	43.0	3.8	39.2	38.7	34.9	4.3	30.4	26.6	12.6
5.500	48.5	5.0	43.5	36.0	31.0	12.5	33.7	28.7	14.8
6.000	51.0	5.8	45.2	42.0	36.2	9.0	33.9	28.1	17.1
6.095	51.2	6.0	45.2	39.3	33.3	11.9	38.5	32.5	12.7
6.190	53.4	6.0	47.4	36.0	30.0	17.4	37.2	31.2	16.2
6.285	54.5	6.0	48.5	38.1	32.1	16.4	37.1	31.1	17.4
6.380	55.7	5.9	49.8	41.8	35.9	13.9	45.3	39.4	10.4
Average						6.8	8.7		

Table C2: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	7.7	1.8	4.5	7.3	1.4	4.9
1.000	12.5	4.5	8.0	10.0	5.5	2.5	8.3	3.8	4.2
1.500	15.2	4.7	10.5	13.7	9.0	1.5	13.0	8.3	2.2
2.000	20.5	5.0	15.5	16.9	11.9	3.6	16.6	11.6	3.9
2.500	24.8	3.5	21.3	18.5	15.0	6.3	17.9	14.4	6.9
3.000	28.1	4.2	23.9	21.7	17.5	6.4	21.4	17.2	6.7
3.500	32.0	5.2	26.8	22.1	16.9	9.9	22.0	16.8	10.0
4.000	37.5	4.0	33.5	27.0	23.0	10.5	26.8	22.8	10.7
4.500	42.2	4.1	38.1	33.5	29.4	8.7	27.3	23.2	14.9
5.000	43.0	3.8	39.2	32.6	28.8	10.4	31.6	27.8	11.4
5.500	48.5	5.0	43.5	32.0	27.0	16.5	33.7	28.7	14.8
6.000	51.0	5.8	45.2	34.3	28.5	16.7	31.9	26.1	19.1
6.095	51.2	6.0	45.2	34.6	28.6	16.6	34.2	28.2	17.0
6.190	53.4	6.0	47.4	36.5	30.5	16.9	35.5	29.5	17.9
6.285	54.5	6.0	48.5	40.2	34.2	14.3	36.8	30.8	17.7
6.380	55.7	5.9	49.8	44.2	38.3	11.5	43.3	37.4	12.4
Average						9.2	10.3		

Table C3: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 2-4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.5	0.6	5.7	6.5	0.6	5.7
1.000	12.5	4.5	8.0	6.5	2.0	6.0	5.6	1.1	6.9
1.500	15.2	4.7	10.5	10.9	6.2	4.3	9.5	4.8	5.7
2.000	20.5	5.0	15.5	14.5	9.5	6.0	12.0	7.0	8.5
2.500	24.8	3.5	21.3	17.9	14.4	6.9	16.8	13.3	8.0
3.000	28.1	4.2	23.9	19.4	15.2	8.7	18.3	14.1	9.8
3.500	32.0	5.2	26.8	21.6	16.4	10.4	22.8	17.6	9.2
4.000	37.5	4.0	33.5	22.8	18.8	14.7	24.6	20.6	12.9
4.500	42.2	4.1	38.1	27.0	22.9	15.2	26.3	22.2	15.9
5.000	43.0	3.8	39.2	30.7	26.9	12.3	33.2	29.4	9.8
5.500	48.5	5.0	43.5	30.0	25.0	18.5	28.0	23.0	20.5
6.000	51.0	5.8	45.2	37.0	31.2	14.0	35.8	30.0	15.2
6.095	51.2	6.0	45.2	39.6	33.6	11.6	32.5	26.5	18.7
6.190	53.4	6.0	47.4	38.4	32.4	15.0	33.0	27.0	20.4
6.285	54.5	6.0	48.5	32.7	26.7	21.8	35.1	29.1	19.4
6.380	55.7	5.9	49.8	37.9	32.0	17.8	41.9	36.0	13.8
Average						11.1	11.8		

Table C4: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 4-6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.5	0.6	5.7	6.2	0.3	6.0
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	7.3	2.6	7.9	6.8	2.1	8.4
2.000	20.5	5.0	15.5	11.0	6.0	9.5	8.9	3.9	11.6
2.500	24.8	3.5	21.3	14.0	10.5	10.8	12.3	8.8	12.5
3.000	28.1	4.2	23.9	16.5	12.3	11.6	14.8	10.6	13.3
3.500	32.0	5.2	26.8	19.0	13.8	13.0	19.6	14.4	12.4
4.000	37.5	4.0	33.5	25.0	21.0	12.5	22.3	18.3	15.2
4.500	42.2	4.1	38.1	28.2	24.1	14.0	27.5	23.4	14.7
5.000	43.0	3.8	39.2	31.2	27.4	11.8	27.0	23.2	16.0
5.500	48.5	5.0	43.5	27.0	22.0	21.5	29.6	24.6	18.9
6.000	51.0	5.8	45.2	32.4	26.6	18.6	34.5	28.7	16.5
6.095	51.2	6.0	45.2	31.5	25.5	19.7	32.0	26.0	19.2
6.190	53.4	6.0	47.4	36.6	30.6	16.8	33.0	27.0	20.4
6.285	54.5	6.0	48.5	37.7	31.7	16.8	33.2	27.2	21.3
6.380	55.7	5.9	49.8	39.9	34.0	15.8	41.5	35.6	14.2
Average						12.6	13.4		

Table C5: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 6-8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	5.5	0.8	9.7	5.0	0.3	10.2
2.000	20.5	5.0	15.5	8.2	3.2	12.3	7.0	2.0	13.5
2.500	24.8	3.5	21.3	10.9	7.4	13.9	9.8	6.3	15.0
3.000	28.1	4.2	23.9	14.2	10.0	13.9	13.3	9.1	14.8
3.500	32.0	5.2	26.8	17.5	12.3	14.5	16.3	11.1	15.7
4.000	37.5	4.0	33.5	20.2	16.2	17.3	19.8	15.8	17.7
4.500	42.2	4.1	38.1	25.9	21.8	16.3	24.0	19.9	18.2
5.000	43.0	3.8	39.2	28.2	24.4	14.8	29.4	25.6	13.6
5.500	48.5	5.0	43.5	26.3	21.3	22.2	26.6	21.6	21.9
6.000	51.0	5.8	45.2	32.8	27.0	18.2	32.0	26.2	19.0
6.095	51.2	6.0	45.2	34.0	28.0	17.2	31.5	25.5	19.7
6.190	53.4	6.0	47.4	34.8	28.8	18.6	30.9	24.9	22.5
6.285	54.5	6.0	48.5	32.7	26.7	21.8	33.9	27.9	20.6
6.380	55.7	5.9	49.8	38.0	32.1	17.7	41.9	36.0	13.8
Average						14.3	14.7		

Table C6: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 8-12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.9	0.9	14.6	5.7	0.7	14.8
2.500	24.8	3.5	21.3	7.8	4.3	17.0	6.5	3.0	18.3
3.000	28.1	4.2	23.9	10.4	6.2	17.7	8.7	4.5	19.4
3.500	32.0	5.2	26.8	14.2	9.0	17.8	12.5	7.3	19.5
4.000	37.5	4.0	33.5	17.2	13.2	20.3	15.4	11.4	22.1
4.500	42.2	4.1	38.1	22.8	18.7	19.4	20.4	16.3	21.8
5.000	43.0	3.8	39.2	25.9	22.1	17.1	25.2	21.4	17.8
5.500	48.5	5.0	43.5	26.7	21.7	21.8	24.2	19.2	24.3
6.000	51.0	5.8	45.2	27.2	21.4	23.8	28.8	23.0	22.2
6.095	51.2	6.0	45.2	28.0	22.0	23.2	30.7	24.7	20.5
6.190	53.4	6.0	47.4	31.4	25.4	22.0	32.9	26.9	20.5
6.285	54.5	6.0	48.5	33.0	27.0	21.5	34.9	28.9	19.6
6.380	55.7	5.9	49.8	41.9	36.0	13.8	42.0	36.1	13.7
Average						16.2	16.4		

Table C7: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 12-23 hours)

Time (hours)	0.0			14.0			23.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.9	0.9	14.6	5.5	0.5	15.0
2.500	24.8	3.5	21.3	5.6	2.1	19.2	3.7	0.2	21.1
3.000	28.1	4.2	23.9	8.0	3.8	20.1	5.7	1.5	22.4
3.500	32.0	5.2	26.8	11.0	5.8	21.0	7.5	2.3	24.5
4.000	37.5	4.0	33.5	14.5	10.5	23.0	8.9	4.9	28.6
4.500	42.2	4.1	38.1	19.5	15.4	22.7	15.0	10.9	27.2
5.000	43.0	3.8	39.2	24.0	20.2	19.0	19.7	15.9	23.3
5.500	48.5	5.0	43.5	23.8	18.8	24.7	20.2	15.2	28.3
6.000	51.0	5.8	45.2	27.2	21.4	23.8	24.2	18.4	26.8
6.095	51.2	6.0	45.2	28.7	22.7	22.5	26.0	20.0	25.2
6.190	53.4	6.0	47.4	30.2	24.2	23.2	26.4	20.4	27.0
6.285	54.5	6.0	48.5	32.5	26.5	22.0	28.6	22.6	25.9
6.380	55.7	5.9	49.8	40.0	34.1	15.7	37.6	31.7	18.1
Average						17.4	19.9		

Table C8: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 23-38 hours)

Time (hours)	0.0			30.0			38.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.5	0.5	15.0	5.5	0.5	15.0
2.500	24.8	3.5	21.3	3.7	0.2	21.1	3.7	0.2	21.1
3.000	28.1	4.2	23.9	5.0	0.8	23.1	4.6	0.4	23.5
3.500	32.0	5.2	26.8	7.2	2.0	24.8	7.2	2.0	24.8
4.000	37.5	4.0	33.5	7.3	3.3	30.2	6.7	2.7	30.8
4.500	42.2	4.1	38.1	12.7	8.6	29.5	10.9	6.8	31.3
5.000	43.0	3.8	39.2	18.1	14.3	24.9	16.0	12.2	27.0
5.500	48.5	5.0	43.5	17.5	12.5	31.0	15.4	10.4	33.1
6.000	51.0	5.8	45.2	23.5	17.7	27.5	21.5	15.7	29.5
6.095	51.2	6.0	45.2	24.6	18.6	26.6	22.7	16.7	28.5
6.190	53.4	6.0	47.4	24.8	18.8	28.6	24.0	18.0	29.4
6.285	54.5	6.0	48.5	26.6	20.6	27.9	25.5	19.5	29.0
6.380	55.7	5.9	49.8	35.7	29.8	20.0	35.3	29.4	20.4
Average						20.9	21.7		

Table C9: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 38-57 hours)

Time (hours)	0.0			47.0			57.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.5	0.5	15.0	5.5	0.5	15.0
2.500	24.8	3.5	21.3	3.7	0.2	21.1	3.7	0.2	21.1
3.000	28.1	4.2	23.9	4.5	0.3	23.6	4.5	0.3	23.6
3.500	32.0	5.2	26.8	6.9	1.7	25.1	5.2	0.0	26.8
4.000	37.5	4.0	33.5	5.4	1.4	32.1	5.0	1.0	32.5
4.500	42.2	4.1	38.1	9.8	5.7	32.4	9.0	4.9	33.2
5.000	43.0	3.8	39.2	14.0	10.2	29.0	13.4	9.6	29.6
5.500	48.5	5.0	43.5	13.9	8.9	34.6	13.5	8.5	35.0
6.000	51.0	5.8	45.2	19.6	13.8	31.4	18.9	13.1	32.1
6.095	51.2	6.0	45.2	21.5	15.5	29.7	20.8	14.8	30.4
6.190	53.4	6.0	47.4	22.2	16.2	31.2	21.5	15.5	31.9
6.285	54.5	6.0	48.5	24.8	18.8	29.7	23.9	17.9	30.6
6.380	55.7	5.9	49.8	36.0	30.1	19.7	35.1	29.2	20.6
						Average	22.3		

Table C10: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 57-71 hours)

Time (hours)	0.0			61.0			71.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.5	0.5	15.0	5.5	0.5	15.0
2.500	24.8	3.5	21.3	3.7	0.2	21.1	3.7	0.2	21.1
3.000	28.1	4.2	23.9	4.5	0.3	23.6	4.5	0.3	23.6
3.500	32.0	5.2	26.8	5.2	0.0	26.8	5.2	0.0	26.8
4.000	37.5	4.0	33.5	5.0	1.0	32.5	4.8	0.8	32.7
4.500	42.2	4.1	38.1	8.7	4.6	33.5	8.0	3.9	34.2
5.000	43.0	3.8	39.2	13.0	9.2	30.0	12.4	8.6	30.6
5.500	48.5	5.0	43.5	13.1	8.1	35.4	12.3	7.3	36.2
6.000	51.0	5.8	45.2	19.4	13.6	31.6	18.2	12.4	32.8
6.095	51.2	6.0	45.2	19.9	13.9	31.3	20.0	14.0	31.2
6.190	53.4	6.0	47.4	21.4	15.4	32.0	20.5	14.5	32.9
6.285	54.5	6.0	48.5	24.0	18.0	30.5	22.8	16.8	31.7
6.380	55.7	5.9	49.8	35.8	29.9	19.9	35.5	29.6	20.2
						Average	22.8		

Table C11: Active storage data (Q_w : 2.85 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 71-95 hours)

Time (hours)	0.0			86.0			95.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	12.2	5.9	6.3	6.0	0.1	6.2	6.0	0.1	6.2
1.000	12.5	4.5	8.0	4.5	0.0	8.0	4.5	0.0	8.0
1.500	15.2	4.7	10.5	4.7	0.0	10.5	4.7	0.0	10.5
2.000	20.5	5.0	15.5	5.5	0.5	15.0	5.5	0.5	15.0
2.500	24.8	3.5	21.3	3.7	0.2	21.1	3.7	0.2	21.1
3.000	28.1	4.2	23.9	4.5	0.3	23.6	4.5	0.3	23.6
3.500	32.0	5.2	26.8	5.2	0.0	26.8	5.2	0.0	26.8
4.000	37.5	4.0	33.5	4.4	0.4	33.1	4.4	0.4	33.1
4.500	42.2	4.1	38.1	7.7	3.6	34.5	7.2	3.1	35.0
5.000	43.0	3.8	39.2	11.9	8.1	31.1	11.4	7.6	31.6
5.500	48.5	5.0	43.5	11.2	6.2	37.3	10.9	5.9	37.6
6.000	51.0	5.8	45.2	15.5	9.7	35.5	16.7	10.9	34.3
6.095	51.2	6.0	45.2	18.3	12.3	32.9	18.4	12.4	32.8
6.190	53.4	6.0	47.4	19.6	13.6	33.8	19.3	13.3	34.1
6.285	54.5	6.0	48.5	22.3	16.3	32.2	22.5	16.5	32.0
6.380	55.7	5.9	49.8	34.6	28.7	21.1	34.0	28.1	21.7
						Average	23.7		

Table C12: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	10.3	4.4	1.1	8.6	2.7	2.8
1.000	15.4	4.5	10.9	14.4	9.9	1.0	12.4	7.9	3.0
1.500	18.7	4.7	14.0	21.7	17.0	-3.0	18.2	13.5	0.5
2.000	20.3	5.0	15.3	17.5	12.5	2.8	18.2	13.2	2.1
2.500	26.5	3.5	23.0	23.4	19.9	3.1	23.9	20.4	2.6
3.000	27.0	4.2	22.8	22.6	18.4	4.4	19.1	14.9	7.9
3.500	33.7	5.2	28.5	27.7	22.5	6.0	26.3	21.1	7.4
4.000	37.5	4.0	33.5	26.9	22.9	10.6	25.2	21.2	12.3
4.500	42.0	4.1	37.9	36.0	31.9	6.0	33.5	29.4	8.5
5.000	45.2	3.8	41.4	37.8	34.0	7.4	36.8	33.0	8.4
5.500	48.4	5.0	43.4	37.8	32.8	10.6	32.0	27.0	16.4
6.000	52.6	5.8	46.8	42.5	36.7	10.1	38.4	32.6	14.2
6.095	54.5	6.0	48.5	41.3	35.3	13.2	39.8	33.8	14.7
6.190	56.3	6.0	50.3	41.8	35.8	14.5	41.3	35.3	15.0
6.285	57.0	6.0	51.0	40.0	34.0	17.0	39.9	33.9	17.1
6.380	56.9	5.9	51.0	42.8	36.9	14.1	44.9	39.0	12.0
						Average	7.0		

Table C13: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	7.2	1.3	4.2	6.9	1.0	4.5
1.000	15.4	4.5	10.9	10.2	5.7	5.2	9.6	5.1	5.8
1.500	18.7	4.7	14.0	15.7	11.0	3.0	14.0	9.3	4.7
2.000	20.3	5.0	15.3	19.3	14.3	1.0	17.4	12.4	2.9
2.500	26.5	3.5	23.0	23.3	19.8	3.2	23.0	19.5	3.5
3.000	27.0	4.2	22.8	24.0	19.8	3.0	21.5	17.3	5.5
3.500	33.7	5.2	28.5	20.2	15.0	13.5	22.8	17.6	10.9
4.000	37.5	4.0	33.5	25.3	21.3	12.2	23.8	19.8	13.7
4.500	42.0	4.1	37.9	33.0	28.9	9.0	24.0	19.9	18.0
5.000	45.2	3.8	41.4	30.0	26.2	15.2	32.4	28.6	12.8
5.500	48.4	5.0	43.4	28.7	23.7	19.7	35.8	30.8	12.6
6.000	52.6	5.8	46.8	34.8	29.0	17.8	30.8	25.0	21.8
6.095	54.5	6.0	48.5	37.0	31.0	17.5	33.0	27.0	21.5
6.190	56.3	6.0	50.3	39.0	33.0	17.3	34.8	28.8	21.5
6.285	57.0	6.0	51.0	40.2	34.2	16.8	35.7	29.7	21.3
6.380	56.9	5.9	51.0	43.1	37.2	13.8	42.8	36.9	14.1
Average						10.1	11.5		

Table C14: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 2-4.08 hours)

Time (hours)	0.0			3.08			4.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	6.7	0.8	4.7	6.3	0.4	5.1
1.000	15.4	4.5	10.9	7.2	2.7	8.2	7.1	2.6	8.3
1.500	18.7	4.7	14.0	11.2	6.5	7.5	11.0	6.3	7.7
2.000	20.3	5.0	15.3	13.4	8.4	6.9	13.0	8.0	7.3
2.500	26.5	3.5	23.0	20.7	17.2	5.8	17.4	13.9	9.1
3.000	27.0	4.2	22.8	18.6	14.4	8.4	18.0	13.8	9.0
3.500	33.7	5.2	28.5	20.5	15.3	13.2	21.3	16.1	12.4
4.000	37.5	4.0	33.5	23.2	19.2	14.3	22.5	18.5	15.0
4.500	42.0	4.1	37.9	32.7	28.6	9.3	25.3	21.2	16.7
5.000	45.2	3.8	41.4	33.3	29.5	11.9	33.5	29.7	11.7
5.500	48.4	5.0	43.4	27.5	22.5	20.9	28.4	23.4	20.0
6.000	52.6	5.8	46.8	34.3	28.5	18.3	32.9	27.1	19.7
6.095	54.5	6.0	48.5	37.5	31.5	17.0	35.9	29.9	18.6
6.190	56.3	6.0	50.3	39.4	33.4	16.9	37.7	31.7	18.6
6.285	57.0	6.0	51.0	38.0	32.0	19.0	39.6	33.6	17.4
6.380	56.9	5.9	51.0	41.2	35.3	15.7	43.2	37.3	13.7
Average						11.6	12.4		

Table C15: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 4.08-6.08 hours)

Time (hours)	0.0			5.08			6.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	6.4	0.5	5.0	6.4	0.5	5.0
1.000	15.4	4.5	10.9	6.8	2.3	8.6	6.0	1.5	9.4
1.500	18.7	4.7	14.0	10.5	5.8	8.2	10.0	5.3	8.7
2.000	20.3	5.0	15.3	11.9	6.9	8.4	11.8	6.8	8.5
2.500	26.5	3.5	23.0	17.0	13.5	9.5	16.3	12.8	10.2
3.000	27.0	4.2	22.8	13.0	8.8	14.0	15.5	11.3	11.5
3.500	33.7	5.2	28.5	20.8	15.6	12.9	17.5	12.3	16.2
4.000	37.5	4.0	33.5	21.0	17.0	16.5	22.0	18.0	15.5
4.500	42.0	4.1	37.9	29.4	25.3	12.6	26.5	22.4	15.5
5.000	45.2	3.8	41.4	28.2	24.4	17.0	29.9	26.1	15.3
5.500	48.4	5.0	43.4	28.7	23.7	19.7	24.5	19.5	23.9
6.000	52.6	5.8	46.8	31.9	26.1	20.7	33.2	27.4	19.4
6.095	54.5	6.0	48.5	33.0	27.0	21.5	36.5	30.5	18.0
6.190	56.3	6.0	50.3	34.4	28.4	21.9	39.3	33.3	17.0
6.285	57.0	6.0	51.0	36.7	30.7	20.3	38.4	32.4	18.6
6.380	56.9	5.9	51.0	42.5	36.6	14.4	43.0	37.1	13.9
Average						13.6	13.3		

Table C16: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 6.08-8.08 hours)

Time (hours)	0.0			7.08			8.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	6.0	0.1	5.4	6.0	0.1	5.4
1.000	15.4	4.5	10.9	5.9	1.4	9.5	5.5	1.0	9.9
1.500	18.7	4.7	14.0	8.3	3.6	10.4	8.1	3.4	10.6
2.000	20.3	5.0	15.3	9.3	4.3	11.0	9.2	4.2	11.1
2.500	26.5	3.5	23.0	16.3	12.8	10.2	15.5	12.0	11.0
3.000	27.0	4.2	22.8	13.4	9.2	13.6	12.0	7.8	15.0
3.500	33.7	5.2	28.5	16.5	11.3	17.2	17.0	11.8	16.7
4.000	37.5	4.0	33.5	20.9	16.9	16.6	18.2	14.2	19.3
4.500	42.0	4.1	37.9	23.2	19.1	18.8	23.6	19.5	18.4
5.000	45.2	3.8	41.4	28.8	25.0	16.4	30.5	26.7	14.7
5.500	48.4	5.0	43.4	29.5	24.5	18.9	26.3	21.3	22.1
6.000	52.6	5.8	46.8	31.4	25.6	21.2	29.8	24.0	22.8
6.095	54.5	6.0	48.5	32.5	26.5	22.0	31.4	25.4	23.1
6.190	56.3	6.0	50.3	33.5	27.5	22.8	32.5	26.5	23.8
6.285	57.0	6.0	51.0	36.0	30.0	21.0	34.0	28.0	23.0
6.380	56.9	5.9	51.0	42.0	36.1	14.9	40.2	34.3	16.7
Average						14.7	15.5		

Table C17: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 8.08-12.08 hours)

Time (hours)	0.0			10.08			12.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	6.0	0.1	5.4	5.9	0.0	5.5
1.000	15.4	4.5	10.9	5.2	0.7	10.2	5.0	0.5	10.4
1.500	18.7	4.7	14.0	7.7	3.0	11.0	7.9	3.2	10.8
2.000	20.3	5.0	15.3	9.2	4.2	11.1	7.7	2.7	12.6
2.500	26.5	3.5	23.0	13.7	10.2	12.8	13.1	9.6	13.4
3.000	27.0	4.2	22.8	11.6	7.4	15.4	12.0	7.8	15.0
3.500	33.7	5.2	28.5	16.2	11.0	17.5	14.5	9.3	19.2
4.000	37.5	4.0	33.5	17.9	13.9	19.6	18.7	14.7	18.8
4.500	42.0	4.1	37.9	23.2	19.1	18.8	21.4	17.3	20.6
5.000	45.2	3.8	41.4	28.4	24.6	16.8	27.4	23.6	17.8
5.500	48.4	5.0	43.4	21.9	16.9	26.5	24.1	19.1	24.3
6.000	52.6	5.8	46.8	32.2	26.4	20.4	28.0	22.2	24.6
6.095	54.5	6.0	48.5	34.0	28.0	20.5	29.8	23.8	24.7
6.190	56.3	6.0	50.3	35.9	29.9	20.4	31.0	25.0	25.3
6.285	57.0	6.0	51.0	36.8	30.8	20.2	31.9	25.9	25.1
6.380	56.9	5.9	51.0	41.0	35.1	15.9	39.0	33.1	17.9
Average						15.4	16.8		

Table C18: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 12.08-20.08 hours)

Time (hours)	0.0			15.08			20.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.9	0.4	10.5	4.6	0.1	10.8
1.500	18.7	4.7	14.0	6.8	2.1	11.9	6.8	2.1	11.9
2.000	20.3	5.0	15.3	7.5	2.5	12.8	8.5	3.5	11.8
2.500	26.5	3.5	23.0	12.3	8.8	14.2	12.2	8.7	14.3
3.000	27.0	4.2	22.8	10.5	6.3	16.5	9.8	5.6	17.2
3.500	33.7	5.2	28.5	13.5	8.3	20.2	12.7	7.5	21.0
4.000	37.5	4.0	33.5	17.6	13.6	19.9	16.3	12.3	21.2
4.500	42.0	4.1	37.9	20.0	15.9	22.0	19.8	15.7	22.2
5.000	45.2	3.8	41.4	26.2	22.4	19.0	24.5	20.7	20.7
5.500	48.4	5.0	43.4	24.0	19.0	24.4	22.0	17.0	26.4
6.000	52.6	5.8	46.8	28.0	22.2	24.6	27.6	21.8	25.0
6.095	54.5	6.0	48.5	29.9	23.9	24.6	29.7	23.7	24.8
6.190	56.3	6.0	50.3	30.9	24.9	25.4	31.0	25.0	25.3
6.285	57.0	6.0	51.0	32.2	26.2	24.8	32.4	26.4	24.6
6.380	56.9	5.9	51.0	39.0	33.1	17.9	40.9	35.0	16.0
Average						17.3	17.6		

Table C19: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 20.08-30.08 hours)

Time (hours)	0.0			25.08			30.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	7.6	2.9	11.1	7.6	2.9	11.1
2.000	20.3	5.0	15.3	7.8	2.8	12.5	8.0	3.0	12.3
2.500	26.5	3.5	23.0	11.8	8.3	14.7	12.8	9.3	13.7
3.000	27.0	4.2	22.8	9.6	5.4	17.4	10.1	5.9	16.9
3.500	33.7	5.2	28.5	11.8	6.6	21.9	12.2	7.0	21.5
4.000	37.5	4.0	33.5	14.5	10.5	23.0	14.0	10.0	23.5
4.500	42.0	4.1	37.9	18.4	14.3	23.6	19.0	14.9	23.0
5.000	45.2	3.8	41.4	24.0	20.2	21.2	23.5	19.7	21.7
5.500	48.4	5.0	43.4	21.7	16.7	26.7	20.3	15.3	28.1
6.000	52.6	5.8	46.8	26.7	20.9	25.9	28.6	22.8	24.0
6.095	54.5	6.0	48.5	28.8	22.8	25.7	30.0	24.0	24.5
6.190	56.3	6.0	50.3	29.6	23.6	26.7	28.2	22.2	28.1
6.285	57.0	6.0	51.0	30.9	24.9	26.1	29.9	23.9	27.1
6.380	56.9	5.9	51.0	39.6	33.7	17.3	38.2	32.3	18.7
Average						18.2	18.3		

Table C20: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 30.08-45.08 hours)

Time (hours)	0.0			35.08			45.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	6.9	2.2	11.8	6.9	2.2	11.8
2.000	20.3	5.0	15.3	7.4	2.4	12.9	8.0	3.0	12.3
2.500	26.5	3.5	23.0	13.0	9.5	13.5	12.0	8.5	14.5
3.000	27.0	4.2	22.8	9.4	5.2	17.6	10.8	6.6	16.2
3.500	33.7	5.2	28.5	12.3	7.1	21.4	12.5	7.3	21.2
4.000	37.5	4.0	33.5	14.0	10.0	23.5	12.5	8.5	25.0
4.500	42.0	4.1	37.9	18.0	13.9	24.0	19.3	15.2	22.7
5.000	45.2	3.8	41.4	23.8	20.0	21.4	19.1	15.3	26.1
5.500	48.4	5.0	43.4	21.0	16.0	27.4	19.0	14.0	29.4
6.000	52.6	5.8	46.8	26.7	20.9	25.9	26.0	20.2	26.6
6.095	54.5	6.0	48.5	28.0	22.0	26.5	27.2	21.2	27.3
6.190	56.3	6.0	50.3	28.0	22.0	28.3	28.4	22.4	27.9
6.285	57.0	6.0	51.0	30.0	24.0	27.0	31.0	25.0	26.0
6.380	56.9	5.9	51.0	38.5	32.6	18.4	39.9	34.0	17.0
Average						18.6	18.8		

Table C21: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 45.08-60.08 hours)

Time (hours)	0.0			52.08			60.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	7.9	3.2	10.8	7.2	2.5	11.5
2.000	20.3	5.0	15.3	8.6	3.6	11.7	7.7	2.7	12.6
2.500	26.5	3.5	23.0	12.7	9.2	13.8	12.0	8.5	14.5
3.000	27.0	4.2	22.8	9.8	5.6	17.2	10.0	5.8	17.0
3.500	33.7	5.2	28.5	12.0	6.8	21.7	11.9	6.7	21.8
4.000	37.5	4.0	33.5	13.2	9.2	24.3	15.2	11.2	22.3
4.500	42.0	4.1	37.9	20.2	16.1	21.8	20.8	16.7	21.2
5.000	45.2	3.8	41.4	22.5	18.7	22.7	22.3	18.5	22.9
5.500	48.4	5.0	43.4	20.9	15.9	27.5	20.0	15.0	28.4
6.000	52.6	5.8	46.8	26.2	20.4	26.4	26.7	20.9	25.9
6.095	54.5	6.0	48.5	27.2	21.2	27.3	28.5	22.5	26.0
6.190	56.3	6.0	50.3	27.6	21.6	28.7	29.3	23.3	27.0
6.285	57.0	6.0	51.0	29.5	23.5	27.5	31.1	25.1	25.9
6.380	56.9	5.9	51.0	37.3	31.4	19.6	38.0	32.1	18.9
Average						18.7	18.4		

Table C22: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 60.08-80.08 hours)

Time (hours)	0.0			70.08			80.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	7.8	3.1	10.9	7.5	2.8	11.2
2.000	20.3	5.0	15.3	8.1	3.1	12.2	8.6	3.6	11.7
2.500	26.5	3.5	23.0	12.0	8.5	14.5	12.0	8.5	14.5
3.000	27.0	4.2	22.8	8.2	4.0	18.8	10.8	6.6	16.2
3.500	33.7	5.2	28.5	12.8	7.6	20.9	12.5	7.3	21.2
4.000	37.5	4.0	33.5	16.0	12.0	21.5	14.1	10.1	23.4
4.500	42.0	4.1	37.9	18.7	14.6	23.3	19.6	15.5	22.4
5.000	45.2	3.8	41.4	22.9	19.1	22.3	24.4	20.6	20.8
5.500	48.4	5.0	43.4	20.3	15.3	28.1	18.5	13.5	29.9
6.000	52.6	5.8	46.8	25.5	19.7	27.1	27.5	21.7	25.1
6.095	54.5	6.0	48.5	26.8	20.8	27.7	28.4	22.4	26.1
6.190	56.3	6.0	50.3	27.8	21.8	28.5	28.2	22.2	28.1
6.285	57.0	6.0	51.0	29.5	23.5	27.5	29.6	23.6	27.4
6.380	56.9	5.9	51.0	39.0	33.1	17.9	37.0	31.1	19.9
Average						18.7	18.5		

Table C23: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 80.08-98.16 hours)

Time (hours)	0.0			96.16			98.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	7.7	3.0	11.0	6.5	1.8	12.2
2.000	20.3	5.0	15.3	8.4	3.4	11.9	7.4	2.4	12.9
2.500	26.5	3.5	23.0	12.7	9.2	13.8	11.3	7.8	15.2
3.000	27.0	4.2	22.8	8.9	4.7	18.1	8.0	3.8	19.0
3.500	33.7	5.2	28.5	11.8	6.6	21.9	12.3	7.1	21.4
4.000	37.5	4.0	33.5	15.4	11.4	22.1	14.6	10.6	22.9
4.500	42.0	4.1	37.9	17.9	13.8	24.1	20.0	15.9	22.0
5.000	45.2	3.8	41.4	23.4	19.6	21.8	23.7	19.9	21.5
5.500	48.4	5.0	43.4	18.2	13.2	30.2	20.5	15.5	27.9
6.000	52.6	5.8	46.8	26.3	20.5	26.3	26.0	20.2	26.6
6.095	54.5	6.0	48.5	28.0	22.0	26.5	27.0	21.0	27.5
6.190	56.3	6.0	50.3	28.6	22.6	27.7	28.4	22.4	27.9
6.285	57.0	6.0	51.0	30.9	24.9	26.1	30.4	24.4	26.6
6.380	56.9	5.9	51.0	39.8	33.9	17.1	36.9	31.0	20.0
Average						18.5	18.8		

Table C24: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 98.16-103.16 hours)

Time (hours)	0.0			100.16			103.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	4.7	0.0	14.0	4.7	0.0	14.0
2.000	20.3	5.0	15.3	6.2	1.2	14.1	5.0	0.0	15.3
2.500	26.5	3.5	23.0	10.0	6.5	16.5	9.5	6.0	17.0
3.000	27.0	4.2	22.8	7.0	2.8	20.0	6.4	2.2	20.6
3.500	33.7	5.2	28.5	11.0	5.8	22.7	10.0	4.8	23.7
4.000	37.5	4.0	33.5	13.5	9.5	24.0	11.3	7.3	26.2
4.500	42.0	4.1	37.9	17.7	13.6	24.3	16.0	11.9	26.0
5.000	45.2	3.8	41.4	23.7	19.9	21.5	22.0	18.2	23.2
5.500	48.4	5.0	43.4	21.2	16.2	27.2	18.5	13.5	29.9
6.000	52.6	5.8	46.8	27.9	22.1	24.7	26.7	20.9	25.9
6.095	54.5	6.0	48.5	28.7	22.7	25.8	28.9	22.9	25.6
6.190	56.3	6.0	50.3	28.8	22.8	27.5	29.2	23.2	27.1
6.285	57.0	6.0	51.0	30.2	24.2	26.8	30.3	24.3	26.7
6.380	56.9	5.9	51.0	39.2	33.3	17.7	37.9	32.0	19.0
Average						19.0	19.8		

Table C25: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 103.16-118.16 hours)

Time (hours)	0.0			107.16			118.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	4.7	0.0	14.0	4.7	0.0	14.0
2.000	20.3	5.0	15.3	5.0	0.0	15.3	5.0	0.0	15.3
2.500	26.5	3.5	23.0	8.0	4.5	18.5	5.0	1.5	21.5
3.000	27.0	4.2	22.8	5.4	1.2	21.6	5.0	0.8	22.0
3.500	33.7	5.2	28.5	8.0	2.8	25.7	5.8	0.6	27.9
4.000	37.5	4.0	33.5	9.8	5.8	27.7	7.5	3.5	30.0
4.500	42.0	4.1	37.9	15.0	10.9	27.0	11.8	7.7	30.2
5.000	45.2	3.8	41.4	21.7	17.9	23.5	17.0	13.2	28.2
5.500	48.4	5.0	43.4	17.5	12.5	30.9	14.5	9.5	33.9
6.000	52.6	5.8	46.8	25.5	19.7	27.1	23.2	17.4	29.4
6.095	54.5	6.0	48.5	27.2	21.2	27.3	24.7	18.7	29.8
6.190	56.3	6.0	50.3	27.7	21.7	28.6	26.0	20.0	30.3
6.285	57.0	6.0	51.0	29.9	23.9	27.1	28.3	22.3	28.7
6.380	56.9	5.9	51.0	38.0	32.1	18.9	37.0	31.1	19.9
Average						20.6	22.2		

Table C26: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 118.16-131.16 hours)

Time (hours)	0.0			125.16			131.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	4.7	0.0	14.0	4.7	0.0	14.0
2.000	20.3	5.0	15.3	5.0	0.0	15.3	5.0	0.0	15.3
2.500	26.5	3.5	23.0	3.7	0.2	22.8	3.5	0.0	23.0
3.000	27.0	4.2	22.8	5.0	0.8	22.0	4.4	0.2	22.6
3.500	33.7	5.2	28.5	5.5	0.3	28.2	6.0	0.8	27.7
4.000	37.5	4.0	33.5	6.7	2.7	30.8	5.9	1.9	31.6
4.500	42.0	4.1	37.9	11.7	7.6	30.3	10.0	5.9	32.0
5.000	45.2	3.8	41.4	16.4	12.6	28.8	16.0	12.2	29.2
5.500	48.4	5.0	43.4	13.2	8.2	35.2	12.0	7.0	36.4
6.000	52.6	5.8	46.8	22.7	16.9	29.9	21.7	15.9	30.9
6.095	54.5	6.0	48.5	23.8	17.8	30.7	23.0	17.0	31.5
6.190	56.3	6.0	50.3	24.1	18.1	32.2	23.7	17.7	32.6
6.285	57.0	6.0	51.0	26.0	20.0	31.0	25.5	19.5	31.5
6.380	56.9	5.9	51.0	36.5	30.6	20.4	37.0	31.1	19.9
Average						22.8	23.2		

Table C27: Active storage data (Q_w : 2.85 litres/sec; Q_s : 1.8 ml/min shut at 96.16 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 131.16-149.16 hours)

Time (hours)	0.0			143.16			149.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.7	8.7	0.0	8.7	0.0	0.0	8.7	0.0	0.0
0.500	11.4	5.9	5.5	5.9	0.0	5.5	5.9	0.0	5.5
1.000	15.4	4.5	10.9	4.5	0.0	10.9	4.5	0.0	10.9
1.500	18.7	4.7	14.0	4.7	0.0	14.0	4.7	0.0	14.0
2.000	20.3	5.0	15.3	5.0	0.0	15.3	5.0	0.0	15.3
2.500	26.5	3.5	23.0	3.5	0.0	23.0	3.5	0.0	23.0
3.000	27.0	4.2	22.8	4.2	0.0	22.8	4.2	0.0	22.8
3.500	33.7	5.2	28.5	5.8	0.6	27.9	5.5	0.3	28.2
4.000	37.5	4.0	33.5	5.5	1.5	32.0	5.0	1.0	32.5
4.500	42.0	4.1	37.9	9.4	5.3	32.6	8.9	4.8	33.1
5.000	45.2	3.8	41.4	14.3	10.5	30.9	13.3	9.5	31.9
5.500	48.4	5.0	43.4	11.0	6.0	37.4	10.4	5.4	38.0
6.000	52.6	5.8	46.8	20.7	14.9	31.9	20.0	14.2	32.6
6.095	54.5	6.0	48.5	22.0	16.0	32.5	21.0	15.0	33.5
6.190	56.3	6.0	50.3	22.6	16.6	33.7	22.3	16.3	34.0
6.285	57.0	6.0	51.0	24.7	18.7	32.3	23.5	17.5	33.5
6.380	56.9	5.9	51.0	36.0	30.1	20.9	36.9	31.0	20.0
Average						23.7	24.0		

Table C28: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	12.0	6.1	-0.3	9.0	3.1	2.7
1.000	13.0	4.5	8.5	14.0	9.5	-1.0	13.0	8.5	0.0
1.500	15.5	4.7	10.8	13.8	9.1	1.7	17.5	12.8	-2.0
2.000	19.0	5.0	14.0	17.6	12.6	1.4	16.3	11.3	2.7
2.500	24.3	3.5	20.8	21.0	17.5	3.3	18.9	15.4	5.4
3.000	28.1	4.2	23.9	21.0	16.8	7.1	21.4	17.2	6.7
3.500	33.2	5.2	28.0	27.2	22.0	6.0	22.3	17.1	10.9
4.000	37.4	4.0	33.4	31.8	27.8	5.6	29.6	25.6	7.8
4.500	40.9	4.1	36.8	36.2	32.1	4.7	29.9	25.8	11.0
5.000	43.9	3.8	40.1	40.8	37.0	3.1	35.7	31.9	8.2
5.500	47.0	5.0	42.0	35.0	30.0	12.0	31.2	26.2	15.8
6.000	51.2	5.8	45.4	39.3	33.5	11.9	37.2	31.4	14.0
6.095	53.0	6.0	47.0	43.6	37.6	9.4	39.9	33.9	13.1
6.190	54.4	6.0	48.4	43.2	37.2	11.2	38.5	32.5	15.9
6.285	56.0	6.0	50.0	43.2	37.2	12.8	42.3	36.3	13.7
6.380	55.4	5.9	49.5	46.8	40.9	8.6	44.5	38.6	10.9
Average						5.7	8.0		

Table C29: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	7.8	1.9	3.9	7.3	1.4	4.4
1.000	13.0	4.5	8.5	11.9	7.4	1.1	10.7	6.2	2.3
1.500	15.5	4.7	10.8	16.3	11.6	-0.8	15.2	10.5	0.3
2.000	19.0	5.0	14.0	18.9	13.9	0.1	18.8	13.8	0.2
2.500	24.3	3.5	20.8	19.7	16.2	4.6	21.0	17.5	3.3
3.000	28.1	4.2	23.9	18.8	14.6	9.3	18.0	13.8	10.1
3.500	33.2	5.2	28.0	21.8	16.6	11.4	19.0	13.8	14.2
4.000	37.4	4.0	33.4	28.2	24.2	9.2	24.8	20.8	12.6
4.500	40.9	4.1	36.8	28.0	23.9	12.9	27.0	22.9	13.9
5.000	43.9	3.8	40.1	31.3	27.5	12.6	35.9	32.1	8.0
5.500	47.0	5.0	42.0	30.9	25.9	16.1	26.8	21.8	20.2
6.000	51.2	5.8	45.4	36.4	30.6	14.8	36.4	30.6	14.8
6.095	53.0	6.0	47.0	36.0	30.0	17.0	37.5	31.5	15.5
6.190	54.4	6.0	48.4	40.0	34.0	14.4	40.0	34.0	14.4
6.285	56.0	6.0	50.0	40.0	34.0	16.0	41.2	35.2	14.8
6.380	55.4	5.9	49.5	46.4	40.5	9.0	44.0	38.1	11.4
Average						8.9	9.4		

Table C30: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 2-4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	6.9	1.0	4.8	7.0	1.1	4.7
1.000	13.0	4.5	8.5	9.0	4.5	4.0	8.5	4.0	4.5
1.500	15.5	4.7	10.8	12.8	8.1	2.7	12.0	7.3	3.5
2.000	19.0	5.0	14.0	17.0	12.0	2.0	15.0	10.0	4.0
2.500	24.3	3.5	20.8	19.9	16.4	4.4	17.8	14.3	6.5
3.000	28.1	4.2	23.9	18.2	14.0	9.9	17.3	13.1	10.8
3.500	33.2	5.2	28.0	24.5	19.3	8.7	23.5	18.3	9.7
4.000	37.4	4.0	33.4	22.7	18.7	14.7	21.9	17.9	15.5
4.500	40.9	4.1	36.8	24.0	19.9	16.9	29.5	25.4	11.4
5.000	43.9	3.8	40.1	28.4	24.6	15.5	29.0	25.2	14.9
5.500	47.0	5.0	42.0	30.3	25.3	16.7	24.4	19.4	22.6
6.000	51.2	5.8	45.4	34.0	28.2	17.2	34.0	28.2	17.2
6.095	53.0	6.0	47.0	34.0	28.0	19.0	34.0	28.0	19.0
6.190	54.4	6.0	48.4	36.0	30.0	18.4	32.9	26.9	21.5
6.285	56.0	6.0	50.0	36.5	30.5	19.5	34.9	28.9	21.1
6.380	55.4	5.9	49.5	43.0	37.1	12.4	40.9	35.0	14.5
Average						11.0	11.8		

Table C31: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 4-6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	7.0	1.1	4.7	6.3	0.4	5.4
1.000	13.0	4.5	8.5	8.2	3.7	4.8	8.0	3.5	5.0
1.500	15.5	4.7	10.8	12.0	7.3	3.5	10.8	6.1	4.7
2.000	19.0	5.0	14.0	13.4	8.4	5.6	12.5	7.5	6.5
2.500	24.3	3.5	20.8	15.2	11.7	9.1	16.3	12.8	8.0
3.000	28.1	4.2	23.9	17.3	13.1	10.8	15.8	11.6	12.3
3.500	33.2	5.2	28.0	21.7	16.5	11.5	19.3	14.1	13.9
4.000	37.4	4.0	33.4	21.7	17.7	15.7	21.0	17.0	16.4
4.500	40.9	4.1	36.8	26.3	22.2	14.6	28.2	24.1	12.7
5.000	43.9	3.8	40.1	29.7	25.9	14.2	31.5	27.7	12.4
5.500	47.0	5.0	42.0	26.9	21.9	20.1	25.8	20.8	21.2
6.000	51.2	5.8	45.4	31.4	25.6	19.8	35.3	29.5	15.9
6.095	53.0	6.0	47.0	33.9	27.9	19.1	36.3	30.3	16.7
6.190	54.4	6.0	48.4	32.9	26.9	21.5	38.5	32.5	15.9
6.285	56.0	6.0	50.0	36.4	30.4	19.6	37.0	31.0	19.0
6.380	55.4	5.9	49.5	42.5	36.6	12.9	40.4	34.5	15.0
Average						12.2	11.8		

Table C32: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 6-8 hours)

Time (hours)	0.0			7.0			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	6.9	1.0	4.8	6.5	0.6	5.2
1.000	13.0	4.5	8.5	8.3	3.8	4.7	7.3	2.8	5.7
1.500	15.5	4.7	10.8	10.5	5.8	5.0	11.0	6.3	4.5
2.000	19.0	5.0	14.0	11.7	6.7	7.3	11.3	6.3	7.7
2.500	24.3	3.5	20.8	15.2	11.7	9.1	14.5	11.0	9.8
3.000	28.1	4.2	23.9	15.0	10.8	13.1	15.0	10.8	13.1
3.500	33.2	5.2	28.0	18.5	13.3	14.7	17.5	12.3	15.7
4.000	37.4	4.0	33.4	19.5	15.5	17.9	19.0	15.0	18.4
4.500	40.9	4.1	36.8	26.3	22.2	14.6	24.5	20.4	16.4
5.000	43.9	3.8	40.1	27.0	23.2	16.9	26.0	22.2	17.9
5.500	47.0	5.0	42.0	27.5	22.5	19.5	25.9	20.9	21.1
6.000	51.2	5.8	45.4	35.9	30.1	15.3	35.0	29.2	16.2
6.095	53.0	6.0	47.0	37.7	31.7	15.3	37.4	31.4	15.6
6.190	54.4	6.0	48.4	36.0	30.0	18.4	32.0	26.0	22.4
6.285	56.0	6.0	50.0	36.6	30.6	19.4	33.9	27.9	22.1
6.380	55.4	5.9	49.5	41.9	36.0	13.5	40.3	34.4	15.1
Average						12.3	13.3		

Table C33: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 8-12 hours)

Time (hours)	0.0			10.0			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	6.9	2.4	6.1	7.3	2.8	5.7
1.500	15.5	4.7	10.8	9.8	5.1	5.7	9.1	4.4	6.4
2.000	19.0	5.0	14.0	11.8	6.8	7.2	9.3	4.3	9.7
2.500	24.3	3.5	20.8	14.0	10.5	10.3	13.6	10.1	10.7
3.000	28.1	4.2	23.9	13.4	9.2	14.7	14.5	10.3	13.6
3.500	33.2	5.2	28.0	14.9	9.7	18.3	14.8	9.6	18.4
4.000	37.4	4.0	33.4	18.5	14.5	18.9	18.8	14.8	18.6
4.500	40.9	4.1	36.8	24.3	20.2	16.6	21.8	17.7	19.1
5.000	43.9	3.8	40.1	26.4	22.6	17.5	27.5	23.7	16.4
5.500	47.0	5.0	42.0	26.9	21.9	20.1	23.3	18.3	23.7
6.000	51.2	5.8	45.4	30.4	24.6	20.8	31.2	25.4	20.0
6.095	53.0	6.0	47.0	32.0	26.0	21.0	33.3	27.3	19.7
6.190	54.4	6.0	48.4	33.0	27.0	21.4	33.4	27.4	21.0
6.285	56.0	6.0	50.0	35.0	29.0	21.0	34.0	28.0	22.0
6.380	55.4	5.9	49.5	40.4	34.5	15.0	40.5	34.6	14.9
Average						14.1	14.5		

Table C34: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 12-21 hours)

Time (hours)	0.0			14.0			21.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	6.5	2.0	6.5	7.0	2.5	6.0
1.500	15.5	4.7	10.8	9.0	4.3	6.5	10.4	5.7	5.1
2.000	19.0	5.0	14.0	9.6	4.6	9.4	10.2	5.2	8.8
2.500	24.3	3.5	20.8	13.7	10.2	10.6	14.9	11.4	9.4
3.000	28.1	4.2	23.9	11.6	7.4	16.5	12.5	8.3	15.6
3.500	33.2	5.2	28.0	13.6	8.4	19.6	17.0	11.8	16.2
4.000	37.4	4.0	33.4	17.0	13.0	20.4	16.5	12.5	20.9
4.500	40.9	4.1	36.8	23.0	18.9	17.9	20.9	16.8	20.0
5.000	43.9	3.8	40.1	24.4	20.6	19.5	25.5	21.7	18.4
5.500	47.0	5.0	42.0	21.9	16.9	25.1	21.5	16.5	25.5
6.000	51.2	5.8	45.4	30.5	24.7	20.7	28.5	22.7	22.7
6.095	53.0	6.0	47.0	32.0	26.0	21.0	29.7	23.7	23.3
6.190	54.4	6.0	48.4	33.3	27.3	21.1	31.0	25.0	23.4
6.285	56.0	6.0	50.0	35.0	29.0	21.0	32.7	26.7	23.3
6.380	55.4	5.9	49.5	41.3	35.4	14.1	41.5	35.6	13.9
Average						15.0	15.2		

Table C35: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 21-32 hours)

Time (hours)	0.0			26.0			32.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	7.0	2.5	6.0	7.0	2.5	6.0
1.500	15.5	4.7	10.8	9.6	4.9	5.9	10.0	5.3	5.5
2.000	19.0	5.0	14.0	10.5	5.5	8.5	11.3	6.3	7.7
2.500	24.3	3.5	20.8	15.5	12.0	8.8	15.9	12.4	8.4
3.000	28.1	4.2	23.9	13.5	9.3	14.6	12.5	8.3	15.6
3.500	33.2	5.2	28.0	14.6	9.4	18.6	16.3	11.1	16.9
4.000	37.4	4.0	33.4	19.0	15.0	18.4	17.5	13.5	19.9
4.500	40.9	4.1	36.8	21.0	16.9	19.9	20.9	16.8	20.0
5.000	43.9	3.8	40.1	26.8	23.0	17.1	25.5	21.7	18.4
5.500	47.0	5.0	42.0	21.8	16.8	25.2	26.0	21.0	21.0
6.000	51.2	5.8	45.4	30.5	24.7	20.7	29.0	23.2	22.2
6.095	53.0	6.0	47.0	32.0	26.0	21.0	31.0	25.0	22.0
6.190	54.4	6.0	48.4	33.9	27.9	20.5	31.8	25.8	22.6
6.285	56.0	6.0	50.0	32.8	26.8	23.2	32.0	26.0	24.0
6.380	55.4	5.9	49.5	38.5	32.6	16.9	40.4	34.5	15.0
Average						14.8	14.8		

Table C36: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 32-47 hours)

Time (hours)	0.0			38.0			47.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	7.0	2.5	6.0	6.8	2.3	6.2
1.500	15.5	4.7	10.8	8.5	3.8	7.0	9.6	4.9	5.9
2.000	19.0	5.0	14.0	10.4	5.4	8.6	9.8	4.8	9.2
2.500	24.3	3.5	20.8	12.8	9.3	11.5	14.6	11.1	9.7
3.000	28.1	4.2	23.9	12.5	8.3	15.6	12.7	8.5	15.4
3.500	33.2	5.2	28.0	14.9	9.7	18.3	15.4	10.2	17.8
4.000	37.4	4.0	33.4	18.2	14.2	19.2	18.9	14.9	18.5
4.500	40.9	4.1	36.8	24.0	19.9	16.9	21.3	17.2	19.6
5.000	43.9	3.8	40.1	24.2	20.4	19.7	26.5	22.7	17.4
5.500	47.0	5.0	42.0	23.5	18.5	23.5	22.6	17.6	24.4
6.000	51.2	5.8	45.4	31.0	25.2	20.2	28.0	22.2	23.2
6.095	53.0	6.0	47.0	31.0	25.0	22.0	29.8	23.8	23.2
6.190	54.4	6.0	48.4	29.6	23.6	24.8	30.6	24.6	23.8
6.285	56.0	6.0	50.0	32.3	26.3	23.7	31.5	25.5	24.5
6.380	55.4	5.9	49.5	40.0	34.1	15.4	40.5	34.6	14.9
Average						15.2	15.3		

Table C37: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 47-62 hours)

Time (hours)	0.0			57.0			62.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	6.7	2.2	6.3	6.5	2.0	6.5
1.500	15.5	4.7	10.8	8.9	4.2	6.6	9.7	5.0	5.8
2.000	19.0	5.0	14.0	10.0	5.0	9.0	9.7	4.7	9.3
2.500	24.3	3.5	20.8	13.5	10.0	10.8	12.7	9.2	11.6
3.000	28.1	4.2	23.9	14.0	9.8	14.1	12.5	8.3	15.6
3.500	33.2	5.2	28.0	13.2	8.0	20.0	14.0	8.8	19.2
4.000	37.4	4.0	33.4	17.0	13.0	20.4	16.4	12.4	21.0
4.500	40.9	4.1	36.8	22.7	18.6	18.2	22.3	18.2	18.6
5.000	43.9	3.8	40.1	26.5	22.7	17.4	24.2	20.4	19.7
5.500	47.0	5.0	42.0	22.7	17.7	24.3	24.3	19.3	22.7
6.000	51.2	5.8	45.4	31.2	25.4	20.0	30.3	24.5	20.9
6.095	53.0	6.0	47.0	32.8	26.8	20.2	28.0	22.0	25.0
6.190	54.4	6.0	48.4	33.2	27.2	21.2	29.0	23.0	25.4
6.285	56.0	6.0	50.0	33.0	27.0	23.0	31.4	25.4	24.6
6.380	55.4	5.9	49.5	40.0	34.1	15.4	39.0	33.1	16.4
Average						14.9	15.8		

Table C38: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 62-78 hours)

Time (hours)	0.0			71.0			78.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	6.7	2.2	6.3	6.9	2.4	6.1
1.500	15.5	4.7	10.8	8.8	4.1	6.7	9.3	4.6	6.2
2.000	19.0	5.0	14.0	9.9	4.9	9.1	9.8	4.8	9.2
2.500	24.3	3.5	20.8	13.7	10.2	10.6	13.9	10.4	10.4
3.000	28.1	4.2	23.9	12.9	8.7	15.2	13.9	9.7	14.2
3.500	33.2	5.2	28.0	13.9	8.7	19.3	14.6	9.4	18.6
4.000	37.4	4.0	33.4	16.2	12.2	21.2	16.6	12.6	20.8
4.500	40.9	4.1	36.8	20.0	15.9	20.9	19.0	14.9	21.9
5.000	43.9	3.8	40.1	25.2	21.4	18.7	23.9	20.1	20.0
5.500	47.0	5.0	42.0	24.5	19.5	22.5	19.9	14.9	27.1
6.000	51.2	5.8	45.4	28.9	23.1	22.3	29.0	23.2	22.2
6.095	53.0	6.0	47.0	29.5	23.5	23.5	30.9	24.9	22.1
6.190	54.4	6.0	48.4	30.6	24.6	23.8	31.9	25.9	22.5
6.285	56.0	6.0	50.0	32.3	26.3	23.7	33.9	27.9	22.1
6.380	55.4	5.9	49.5	39.0	33.1	16.4	40.0	34.1	15.4
Average						15.6	15.6		

Table C39: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 78-96 hours)

Time (hours)	0.0			86.0			96.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	6.3	1.8	6.7	6.5	2.0	6.5
1.500	15.5	4.7	10.8	9.0	4.3	6.5	8.9	4.2	6.6
2.000	19.0	5.0	14.0	10.5	5.5	8.5	10.3	5.3	8.7
2.500	24.3	3.5	20.8	13.5	10.0	10.8	13.0	9.5	11.3
3.000	28.1	4.2	23.9	13.1	8.9	15.0	12.9	8.7	15.2
3.500	33.2	5.2	28.0	15.0	9.8	18.2	15.0	9.8	18.2
4.000	37.4	4.0	33.4	16.9	12.9	20.5	15.0	11.0	22.4
4.500	40.9	4.1	36.8	19.7	15.6	21.2	21.4	17.3	19.5
5.000	43.9	3.8	40.1	25.0	21.2	18.9	23.8	20.0	20.1
5.500	47.0	5.0	42.0	23.7	18.7	23.3	21.8	16.8	25.2
6.000	51.2	5.8	45.4	29.1	23.3	22.1	30.0	24.2	21.2
6.095	53.0	6.0	47.0	30.5	24.5	22.5	31.8	25.8	21.2
6.190	54.4	6.0	48.4	32.0	26.0	22.4	33.0	27.0	21.4
6.285	56.0	6.0	50.0	33.3	27.3	22.7	34.7	28.7	21.3
6.380	55.4	5.9	49.5	40.6	34.7	14.8	40.9	35.0	14.5
Average						15.3	15.2		

Table C40: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min shut at 96 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 96-100 hours)

Time (hours)	0.0			98.0			100.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	4.5	0.0	8.5	4.5	0.0	8.5
1.500	15.5	4.7	10.8	7.9	3.2	7.6	6.1	1.4	9.4
2.000	19.0	5.0	14.0	9.5	4.5	9.5	7.7	2.7	11.3
2.500	24.3	3.5	20.8	13.4	9.9	10.9	11.5	8.0	12.8
3.000	28.1	4.2	23.9	11.0	6.8	17.1	9.7	5.5	18.4
3.500	33.2	5.2	28.0	14.0	8.8	19.2	12.8	7.6	20.4
4.000	37.4	4.0	33.4	17.0	13.0	20.4	14.8	10.8	22.6
4.500	40.9	4.1	36.8	22.7	18.6	18.2	20.1	16.0	20.8
5.000	43.9	3.8	40.1	26.0	22.2	17.9	24.7	20.9	19.2
5.500	47.0	5.0	42.0	20.7	15.7	26.3	22.1	17.1	24.9
6.000	51.2	5.8	45.4	29.5	23.7	21.7	30.4	24.6	20.8
6.095	53.0	6.0	47.0	31.1	25.1	21.9	32.5	26.5	20.5
6.190	54.4	6.0	48.4	32.5	26.5	21.9	32.8	26.8	21.6
6.285	56.0	6.0	50.0	33.0	27.0	23.0	34.7	28.7	21.3
6.380	55.4	5.9	49.5	40.0	34.1	15.4	40.7	34.8	14.7
Average						15.6	16.1		

Table C41: Active storage data (Q_w : 2.85 litres/sec; Q_s =2.5 ml/min shut at 96 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 100-110 hours)

Time (hours)	0.0			104.0			110.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	4.5	0.0	8.5	4.5	0.0	8.5
1.500	15.5	4.7	10.8	4.7	0.0	10.8	4.7	0.0	10.8
2.000	19.0	5.0	14.0	6.5	1.5	12.5	5.0	0.0	14.0
2.500	24.3	3.5	20.8	10.2	6.7	14.1	7.4	3.9	16.9
3.000	28.1	4.2	23.9	7.3	3.1	20.8	4.2	0.0	23.9
3.500	33.2	5.2	28.0	11.0	5.8	22.2	7.7	2.5	25.5
4.000	37.4	4.0	33.4	12.7	8.7	24.7	9.9	5.9	27.5
4.500	40.9	4.1	36.8	18.0	13.9	22.9	15.3	11.2	25.6
5.000	43.9	3.8	40.1	23.2	19.4	20.7	20.0	16.2	23.9
5.500	47.0	5.0	42.0	19.7	14.7	27.3	18.0	13.0	29.0
6.000	51.2	5.8	45.4	28.0	22.2	23.2	25.5	19.7	25.7
6.095	53.0	6.0	47.0	30.2	24.2	22.8	27.3	21.3	25.7
6.190	54.4	6.0	48.4	31.0	25.0	23.4	28.5	22.5	25.9
6.285	56.0	6.0	50.0	32.5	26.5	23.5	30.9	24.9	25.1
6.380	55.4	5.9	49.5	39.6	33.7	15.8	39.0	33.1	16.4
Average						17.6	19.4		

Table C42: Active storage data (Q_w : 2.85 litres/sec; Q_s =2.5 ml/min shut at 96 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 110-127 hours)

Time (hours)	0.0			120.0			127.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	4.5	0.0	8.5	4.5	0.0	8.5
1.500	15.5	4.7	10.8	4.7	0.0	10.8	4.7	0.0	10.8
2.000	19.0	5.0	14.0	5.0	0.0	14.0	5.0	0.0	14.0
2.500	24.3	3.5	20.8	6.0	2.5	18.3	4.9	1.4	19.4
3.000	28.1	4.2	23.9	5.0	0.8	23.1	4.9	0.7	23.2
3.500	33.2	5.2	28.0	6.5	1.3	26.7	5.8	0.6	27.4
4.000	37.4	4.0	33.4	7.6	3.6	29.8	6.9	2.9	30.5
4.500	40.9	4.1	36.8	12.8	8.7	28.1	11.9	7.8	29.0
5.000	43.9	3.8	40.1	16.4	12.6	27.5	15.9	12.1	28.0
5.500	47.0	5.0	42.0	14.8	9.8	32.2	13.4	8.4	33.6
6.000	51.2	5.8	45.4	23.9	18.1	27.3	22.5	16.7	28.7
6.095	53.0	6.0	47.0	26.0	20.0	27.0	24.3	18.3	28.7
6.190	54.4	6.0	48.4	27.0	21.0	27.4	25.4	19.4	29.0
6.285	56.0	6.0	50.0	28.9	22.9	27.1	27.2	21.2	28.8
6.380	55.4	5.9	49.5	38.6	32.7	16.8	37.0	31.1	18.4
Average						20.6	21.4		

Table C43: Active storage data (Q_w : 2.85 litres/sec; Q_s : 2.5 ml/min shut at 96 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 127-144 hours)

Time (hours)	0.0			134.0			144.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.9	8.9	0.0	8.9	0.0	0.0	8.9	0.0	0.0
0.500	11.7	5.9	5.8	5.9	0.0	5.8	5.9	0.0	5.8
1.000	13.0	4.5	8.5	4.5	0.0	8.5	4.5	0.0	8.5
1.500	15.5	4.7	10.8	4.7	0.0	10.8	4.7	0.0	10.8
2.000	19.0	5.0	14.0	5.0	0.0	14.0	5.0	0.0	14.0
2.500	24.3	3.5	20.8	3.5	0.0	20.8	3.5	0.0	20.8
3.000	28.1	4.2	23.9	4.2	0.0	23.9	4.2	0.0	23.9
3.500	33.2	5.2	28.0	5.7	0.5	27.5	5.9	0.7	27.3
4.000	37.4	4.0	33.4	5.9	1.9	31.5	5.4	1.4	32.0
4.500	40.9	4.1	36.8	10.8	6.7	30.1	10.0	5.9	30.9
5.000	43.9	3.8	40.1	15.0	11.2	28.9	14.9	11.1	29.0
5.500	47.0	5.0	42.0	12.3	7.3	34.7	12.0	7.0	35.0
6.000	51.2	5.8	45.4	22.0	16.2	29.2	21.0	15.2	30.2
6.095	53.0	6.0	47.0	23.7	17.7	29.3	22.5	16.5	30.5
6.190	54.4	6.0	48.4	24.4	18.4	30.0	23.5	17.5	30.9
6.285	56.0	6.0	50.0	26.7	20.7	29.3	26.1	20.1	29.9
6.380	55.4	5.9	49.5	37.0	31.1	18.4	36.8	30.9	18.6
Average						21.9	22.2		

Table C44: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	12.0	6.1	0.1	10.9	5.0	1.2
1.000	11.4	4.5	6.9	12.4	7.9	-1.0	14.0	9.5	-2.6
1.500	16.1	4.7	11.4	15.0	10.3	1.1	15.9	11.2	0.2
2.000	20.2	5.0	15.2	17.3	12.3	2.9	15.5	10.5	4.7
2.500	23.8	3.5	20.3	23.3	19.8	0.5	20.3	16.8	3.5
3.000	28.0	4.2	23.8	23.3	19.1	4.7	22.9	18.7	5.1
3.500	32.9	5.2	27.7	29.7	24.5	3.2	25.0	19.8	7.9
4.000	38.2	4.0	34.2	29.6	25.6	8.6	26.9	22.9	11.3
4.500	41.9	4.1	37.8	34.5	30.4	7.4	29.8	25.7	12.1
5.000	44.7	3.8	40.9	36.5	32.7	8.2	32.3	28.5	12.4
5.500	48.7	5.0	43.7	35.8	30.8	12.9	36.5	31.5	12.2
6.000	52.1	5.8	46.3	42.5	36.7	9.6	35.4	29.6	16.7
6.095	53.9	6.0	47.9	38.9	32.9	15.0	38.5	32.5	15.4
6.190	55.2	6.0	49.2	43.2	37.2	12.0	40.9	34.9	14.3
6.285	56.0	6.0	50.0	40.9	34.9	15.1	41.6	35.6	14.4
6.380	56.0	5.9	50.1	45.5	39.6	10.5	43.4	37.5	12.6
Average						6.5	8.3		

Table C45: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.2	4.3	1.9	10.0	4.1	2.1
1.000	11.4	4.5	6.9	13.0	8.5	-1.6	12.0	7.5	-0.6
1.500	16.1	4.7	11.4	18.4	13.7	-2.3	15.7	11.0	0.4
2.000	20.2	5.0	15.2	20.7	15.7	-0.5	17.0	12.0	3.2
2.500	23.8	3.5	20.3	21.5	18.0	2.3	20.5	17.0	3.3
3.000	28.0	4.2	23.8	17.9	13.7	10.1	17.8	13.6	10.2
3.500	32.9	5.2	27.7	23.2	18.0	9.7	18.5	13.3	14.4
4.000	38.2	4.0	34.2	28.4	24.4	9.8	25.0	21.0	13.2
4.500	41.9	4.1	37.8	30.5	26.4	11.4	28.7	24.6	13.2
5.000	44.7	3.8	40.9	33.5	29.7	11.2	34.4	30.6	10.3
5.500	48.7	5.0	43.7	28.8	23.8	19.9	29.7	24.7	19.0
6.000	52.1	5.8	46.3	36.7	30.9	15.4	33.9	28.1	18.2
6.095	53.9	6.0	47.9	40.3	34.3	13.6	36.7	30.7	17.2
6.190	55.2	6.0	49.2	34.7	28.7	20.5	34.9	28.9	20.3
6.285	56.0	6.0	50.0	37.0	31.0	19.0	38.4	32.4	17.6
6.380	56.0	5.9	50.1	42.5	36.6	13.5	40.3	34.4	15.7
Average						9.1	10.5		

Table C46: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 2-4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	9.9	4.0	2.2	9.8	3.9	2.3
1.000	11.4	4.5	6.9	13.0	8.5	-1.6	11.9	7.4	-0.5
1.500	16.1	4.7	11.4	15.2	10.5	0.9	16.3	11.6	-0.2
2.000	20.2	5.0	15.2	16.2	11.2	4.0	15.5	10.5	4.7
2.500	23.8	3.5	20.3	18.0	14.5	5.8	20.0	16.5	3.8
3.000	28.0	4.2	23.8	17.2	13.0	10.8	18.9	14.7	9.1
3.500	32.9	5.2	27.7	22.0	16.8	10.9	19.9	14.7	13.0
4.000	38.2	4.0	34.2	20.8	16.8	17.4	23.7	19.7	14.5
4.500	41.9	4.1	37.8	20.9	16.8	21.0	22.8	18.7	19.1
5.000	44.7	3.8	40.9	25.3	21.5	19.4	25.4	21.6	19.3
5.500	48.7	5.0	43.7	28.5	23.5	20.2	25.5	20.5	23.2
6.000	52.1	5.8	46.3	36.7	30.9	15.4	29.0	23.2	23.1
6.095	53.9	6.0	47.9	39.0	33.0	14.9	30.3	24.3	23.6
6.190	55.2	6.0	49.2	38.0	32.0	17.2	34.0	28.0	21.2
6.285	56.0	6.0	50.0	39.0	33.0	17.0	36.7	30.7	19.3
6.380	56.0	5.9	50.1	41.9	36.0	14.1	40.5	34.6	15.5
Average						11.2	12.4		

Table C47: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 4-6 hours)

Time (hours)	0.0			5.0			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	9.3	3.4	2.8	9.8	3.9	2.3
1.000	11.4	4.5	6.9	12.0	7.5	-0.6	12.2	7.7	-0.8
1.500	16.1	4.7	11.4	14.8	10.1	1.3	14.5	9.8	1.6
2.000	20.2	5.0	15.2	15.0	10.0	5.2	17.3	12.3	2.9
2.500	23.8	3.5	20.3	21.0	17.5	2.8	21.0	17.5	2.8
3.000	28.0	4.2	23.8	19.0	14.8	9.0	16.4	12.2	11.6
3.500	32.9	5.2	27.7	17.9	12.7	15.0	20.4	15.2	12.5
4.000	38.2	4.0	34.2	23.9	19.9	14.3	23.9	19.9	14.3
4.500	41.9	4.1	37.8	24.9	20.8	17.0	28.5	24.4	13.4
5.000	44.7	3.8	40.9	28.0	24.2	16.7	30.2	26.4	14.5
5.500	48.7	5.0	43.7	26.0	21.0	22.7	25.5	20.5	23.2
6.000	52.1	5.8	46.3	35.6	29.8	16.5	35.7	29.9	16.4
6.095	53.9	6.0	47.9	36.9	30.9	17.0	36.0	30.0	17.9
6.190	55.2	6.0	49.2	30.8	24.8	24.4	31.8	25.8	23.4
6.285	56.0	6.0	50.0	34.4	28.4	21.6	33.1	27.1	22.9
6.380	56.0	5.9	50.1	41.8	35.9	14.2	38.4	32.5	17.6
Average						11.8	11.6		

Table C48: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 6-8.08 hours)

Time (hours)	0.0			7.0			8.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	9.7	3.8	2.4	9.8	3.9	2.3
1.000	11.4	4.5	6.9	13.0	8.5	-1.6	12.3	7.8	-0.9
1.500	16.1	4.7	11.4	16.4	11.7	-0.3	13.7	9.0	2.4
2.000	20.2	5.0	15.2	15.4	10.4	4.8	15.0	10.0	5.2
2.500	23.8	3.5	20.3	19.4	15.9	4.4	16.0	12.5	7.8
3.000	28.0	4.2	23.8	18.5	14.3	9.5	19.9	15.7	8.1
3.500	32.9	5.2	27.7	19.6	14.4	13.3	21.0	15.8	11.9
4.000	38.2	4.0	34.2	24.9	20.9	13.3	23.0	19.0	15.2
4.500	41.9	4.1	37.8	26.5	22.4	15.4	24.4	20.3	17.5
5.000	44.7	3.8	40.9	28.1	24.3	16.6	29.5	25.7	15.2
5.500	48.7	5.0	43.7	24.6	19.6	24.1	27.4	22.4	21.3
6.000	52.1	5.8	46.3	33.2	27.4	18.9	31.0	25.2	21.1
6.095	53.9	6.0	47.9	35.0	29.0	18.9	32.2	26.2	21.7
6.190	55.2	6.0	49.2	34.9	28.9	20.3	34.8	28.8	20.4
6.285	56.0	6.0	50.0	32.6	26.6	23.4	36.9	30.9	19.1
6.380	56.0	5.9	50.1	39.7	33.8	16.3	43.0	37.1	13.0
Average						11.7	11.8		

Table C49: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8.08-12.08 hours)

Time (hours)	0.0			10.08			12.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.7	4.8	1.4	10.0	4.1	2.1
1.000	11.4	4.5	6.9	13.0	8.5	-1.6	12.0	7.5	-0.6
1.500	16.1	4.7	11.4	16.4	11.7	-0.3	14.9	10.2	1.2
2.000	20.2	5.0	15.2	17.5	12.5	2.7	15.0	10.0	5.2
2.500	23.8	3.5	20.3	19.4	15.9	4.4	20.3	16.8	3.5
3.000	28.0	4.2	23.8	17.7	13.5	10.3	20.0	15.8	8.0
3.500	32.9	5.2	27.7	20.0	14.8	12.9	17.9	12.7	15.0
4.000	38.2	4.0	34.2	22.6	18.6	15.6	22.8	18.8	15.4
4.500	41.9	4.1	37.8	27.3	23.2	14.6	27.2	23.1	14.7
5.000	44.7	3.8	40.9	28.5	24.7	16.2	26.6	22.8	18.1
5.500	48.7	5.0	43.7	25.4	20.4	23.3	25.0	20.0	23.7
6.000	52.1	5.8	46.3	29.6	23.8	22.5	28.5	22.7	23.6
6.095	53.9	6.0	47.9	30.5	24.5	23.4	30.6	24.6	23.3
6.190	55.2	6.0	49.2	32.0	26.0	23.2	32.0	26.0	23.2
6.285	56.0	6.0	50.0	34.0	28.0	22.0	34.0	28.0	22.0
6.380	56.0	5.9	50.1	39.3	33.4	16.7	40.8	34.9	15.2
Average						12.2	12.6		

Table C50: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12.08-20.08 hours)

Time (hours)	0.0			13.08			20.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.0	4.1	2.1	10.0	4.1	2.1
1.000	11.4	4.5	6.9	13.0	8.5	-1.6	13.0	8.5	-1.6
1.500	16.1	4.7	11.4	16.3	11.6	-0.2	15.5	10.8	0.6
2.000	20.2	5.0	15.2	15.4	10.4	4.8	17.8	12.8	2.4
2.500	23.8	3.5	20.3	19.6	16.1	4.2	18.5	15.0	5.3
3.000	28.0	4.2	23.8	17.0	12.8	11.0	18.5	14.3	9.5
3.500	32.9	5.2	27.7	18.0	12.8	14.9	18.9	13.7	14.0
4.000	38.2	4.0	34.2	22.9	18.9	15.3	21.2	17.2	17.0
4.500	41.9	4.1	37.8	22.9	18.8	19.0	23.0	18.9	18.9
5.000	44.7	3.8	40.9	29.3	25.5	15.4	30.4	26.6	14.3
5.500	48.7	5.0	43.7	27.5	22.5	21.2	25.2	20.2	23.5
6.000	52.1	5.8	46.3	32.0	26.2	20.1	32.8	27.0	19.3
6.095	53.9	6.0	47.9	33.0	27.0	20.9	34.4	28.4	19.5
6.190	55.2	6.0	49.2	35.4	29.4	19.8	36.5	30.5	18.7
6.285	56.0	6.0	50.0	31.9	25.9	24.1	37.8	31.8	18.2
6.380	56.0	5.9	50.1	38.7	32.8	17.3	43.6	37.7	12.4
Average						12.3	11.4		

Table C51: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 20.08-36.08 hours)

Time (hours)	0.0			27.08			36.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.7	4.8	1.4	8.5	2.6	3.6
1.000	11.4	4.5	6.9	11.7	7.2	-0.3	12.3	7.8	-0.9
1.500	16.1	4.7	11.4	16.0	11.3	0.1	15.7	11.0	0.4
2.000	20.2	5.0	15.2	17.9	12.9	2.3	17.0	12.0	3.2
2.500	23.8	3.5	20.3	17.8	14.3	6.0	17.2	13.7	6.6
3.000	28.0	4.2	23.8	17.8	13.6	10.2	20.7	16.5	7.3
3.500	32.9	5.2	27.7	19.1	13.9	13.8	20.8	15.6	12.1
4.000	38.2	4.0	34.2	20.9	16.9	17.3	20.0	16.0	18.2
4.500	41.9	4.1	37.8	24.5	20.4	17.4	26.7	22.6	15.2
5.000	44.7	3.8	40.9	29.0	25.2	15.7	29.2	25.4	15.5
5.500	48.7	5.0	43.7	26.8	21.8	21.9	26.7	21.7	22.0
6.000	52.1	5.8	46.3	31.4	25.6	20.7	35.5	29.7	16.6
6.095	53.9	6.0	47.9	32.3	26.3	21.6	36.2	30.2	17.7
6.190	55.2	6.0	49.2	35.6	29.6	19.6	37.7	31.7	17.5
6.285	56.0	6.0	50.0	36.6	30.6	19.4	38.0	32.0	18.0
6.380	56.0	5.9	50.1	38.5	32.6	17.5	39.0	33.1	17.0
Average						12.0	11.2		

Table C52: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 36.08-53.08 hours)

Time (hours)	0.0			44.08			53.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.0	4.1	2.1	10.3	4.4	1.8
1.000	11.4	4.5	6.9	13.7	9.2	-2.3	12.8	8.3	-1.4
1.500	16.1	4.7	11.4	17.0	12.3	-0.9	15.5	10.8	0.6
2.000	20.2	5.0	15.2	18.0	13.0	2.2	16.3	11.3	3.9
2.500	23.8	3.5	20.3	20.4	16.9	3.4	21.0	17.5	2.8
3.000	28.0	4.2	23.8	20.0	15.8	8.0	18.0	13.8	10.0
3.500	32.9	5.2	27.7	23.0	17.8	9.9	19.4	14.2	13.5
4.000	38.2	4.0	34.2	21.4	17.4	16.8	21.4	17.4	16.8
4.500	41.9	4.1	37.8	24.0	19.9	17.9	23.5	19.4	18.4
5.000	44.7	3.8	40.9	26.3	22.5	18.4	27.7	23.9	17.0
5.500	48.7	5.0	43.7	29.1	24.1	19.6	26.3	21.3	22.4
6.000	52.1	5.8	46.3	33.4	27.6	18.7	33.2	27.4	18.9
6.095	53.9	6.0	47.9	33.7	27.7	20.2	34.5	28.5	19.4
6.190	55.2	6.0	49.2	33.7	27.7	21.5	33.2	27.2	22.0
6.285	56.0	6.0	50.0	35.3	29.3	20.7	35.1	29.1	20.9
6.380	56.0	5.9	50.1	41.5	35.6	14.5	42.1	36.2	13.9
Average						11.2	11.8		

Table C53: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 53.08-69.08 hours)

Time (hours)	0.0			60.08			69.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.0	4.1	2.1	10.5	4.6	1.6
1.000	11.4	4.5	6.9	13.5	9.0	-2.1	13.7	9.2	-2.3
1.500	16.1	4.7	11.4	16.7	12.0	-0.6	17.7	13.0	-1.6
2.000	20.2	5.0	15.2	17.0	12.0	3.2	18.2	13.2	2.0
2.500	23.8	3.5	20.3	19.0	15.5	4.8	19.1	15.6	4.7
3.000	28.0	4.2	23.8	19.5	15.3	8.5	20.7	16.5	7.3
3.500	32.9	5.2	27.7	19.0	13.8	13.9	22.0	16.8	10.9
4.000	38.2	4.0	34.2	21.0	17.0	17.2	21.8	17.8	16.4
4.500	41.9	4.1	37.8	25.8	21.7	16.1	28.2	24.1	13.7
5.000	44.7	3.8	40.9	29.0	25.2	15.7	26.7	22.9	18.0
5.500	48.7	5.0	43.7	26.9	21.9	21.8	29.7	24.7	19.0
6.000	52.1	5.8	46.3	31.7	25.9	20.4	31.4	25.6	20.7
6.095	53.9	6.0	47.9	33.0	27.0	20.9	32.4	26.4	21.5
6.190	55.2	6.0	49.2	35.0	29.0	20.2	35.2	29.2	20.0
6.285	56.0	6.0	50.0	33.9	27.9	22.1	36.0	30.0	20.0
6.380	56.0	5.9	50.1	40.5	34.6	15.5	37.4	31.5	18.6
Average						11.7	11.2		

Table C54: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b : 100 mm; Measuring times range: 69.08-84.58 hours)

Time (hours)	0.0			77.08			84.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	10.8	4.9	1.3	10.4	4.5	1.7
1.000	11.4	4.5	6.9	12.5	8.0	-1.1	13.8	9.3	-2.4
1.500	16.1	4.7	11.4	16.6	11.9	-0.5	17.2	12.5	-1.1
2.000	20.2	5.0	15.2	17.1	12.1	3.1	18.9	13.9	1.3
2.500	23.8	3.5	20.3	20.2	16.7	3.6	20.9	17.4	2.9
3.000	28.0	4.2	23.8	18.5	14.3	9.5	21.0	16.8	7.0
3.500	32.9	5.2	27.7	19.9	14.7	13.0	19.7	14.5	13.2
4.000	38.2	4.0	34.2	22.7	18.7	15.5	20.7	16.7	17.5
4.500	41.9	4.1	37.8	24.7	20.6	17.2	25.2	21.1	16.7
5.000	44.7	3.8	40.9	28.6	24.8	16.1	30.2	26.4	14.5
5.500	48.7	5.0	43.7	25.5	20.5	23.2	27.9	22.9	20.8
6.000	52.1	5.8	46.3	31.0	25.2	21.1	30.0	24.2	22.1
6.095	53.9	6.0	47.9	32.8	26.8	21.1	31.0	25.0	22.9
6.190	55.2	6.0	49.2	34.9	28.9	20.3	33.0	27.0	22.2
6.285	56.0	6.0	50.0	36.5	30.5	19.5	35.5	29.5	20.5
6.380	56.0	5.9	50.1	39.9	34.0	16.1	41.5	35.6	14.5
Average						11.7	11.4		

Table C55: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 84.58-100.58 hours)

Time (hours)	0.0			94.58			100.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	9.9	4.0	2.2	10.0	4.1	2.1
1.000	11.4	4.5	6.9	12.8	8.3	-1.4	14.0	9.5	-2.6
1.500	16.1	4.7	11.4	15.5	10.8	0.6	16.7	12.0	-0.6
2.000	20.2	5.0	15.2	18.7	13.7	1.5	18.4	13.4	1.8
2.500	23.8	3.5	20.3	19.1	15.6	4.7	22.5	19.0	1.3
3.000	28.0	4.2	23.8	20.8	16.6	7.2	20.7	16.5	7.3
3.500	32.9	5.2	27.7	21.8	16.6	11.1	22.9	17.7	10.0
4.000	38.2	4.0	34.2	25.0	21.0	13.2	23.0	19.0	15.2
4.500	41.9	4.1	37.8	27.3	23.2	14.6	26.3	22.2	15.6
5.000	44.7	3.8	40.9	30.2	26.4	14.5	31.0	27.2	13.7
5.500	48.7	5.0	43.7	27.3	22.3	21.4	27.5	22.5	21.2
6.000	52.1	5.8	46.3	32.0	26.2	20.1	31.9	26.1	20.2
6.095	53.9	6.0	47.9	33.7	27.7	20.2	32.6	26.6	21.3
6.190	55.2	6.0	49.2	36.3	30.3	18.9	35.3	29.3	19.9
6.285	56.0	6.0	50.0	37.0	31.0	19.0	36.3	30.3	19.7
6.380	56.0	5.9	50.1	39.6	33.7	16.4	40.1	34.2	15.9
Average						10.8	10.7		

Table C56: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 100.58-104.58 hours)

Time (hours)	0.0			102.58			104.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8	6.3	0.4	5.8
1.000	11.4	4.5	6.9	7.0	2.5	4.4	5.8	1.3	5.6
1.500	16.1	4.7	11.4	9.8	5.1	6.3	7.7	3.0	8.4
2.000	20.2	5.0	15.2	12.5	7.5	7.7	9.0	4.0	11.2
2.500	23.8	3.5	20.3	17.5	14.0	6.3	13.7	10.2	10.1
3.000	28.0	4.2	23.8	18.0	13.8	10.0	13.8	9.6	14.2
3.500	32.9	5.2	27.7	22.5	17.3	10.4	18.0	12.8	14.9
4.000	38.2	4.0	34.2	25.3	21.3	12.9	21.5	17.5	16.7
4.500	41.9	4.1	37.8	30.5	26.4	11.4	26.9	22.8	15.0
5.000	44.7	3.8	40.9	26.0	22.2	18.7	30.0	26.2	14.7
5.500	48.7	5.0	43.7	25.4	20.4	23.3	30.5	25.5	18.2
6.000	52.1	5.8	46.3	35.8	30.0	16.3	35.2	29.4	16.9
6.095	53.9	6.0	47.9	36.0	30.0	17.9	36.3	30.3	17.6
6.190	55.2	6.0	49.2	31.9	25.9	23.3	37.7	31.7	17.5
6.285	56.0	6.0	50.0	34.2	28.2	21.8	36.2	30.2	19.8
6.380	56.0	5.9	50.1	39.5	33.6	16.5	39.4	33.5	16.6
Average						12.5	13.1		

Table C57: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 104.58-117.58 hours)

Time (hours)	0.0			107.58			117.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8	6.3	0.4	5.8
1.000	11.4	4.5	6.9	4.5	0.0	6.9	4.5	0.0	6.9
1.500	16.1	4.7	11.4	5.5	0.8	10.6	4.7	0.0	11.4
2.000	20.2	5.0	15.2	6.7	1.7	13.5	5.6	0.6	14.6
2.500	23.8	3.5	20.3	9.6	6.1	14.2	6.9	3.4	16.9
3.000	28.0	4.2	23.8	10.5	6.3	17.5	5.1	0.9	22.9
3.500	32.9	5.2	27.7	14.0	8.8	18.9	8.6	3.4	24.3
4.000	38.2	4.0	34.2	16.5	12.5	21.7	9.8	5.8	28.4
4.500	41.9	4.1	37.8	23.0	18.9	18.9	14.8	10.7	27.1
5.000	44.7	3.8	40.9	27.8	24.0	16.9	19.4	15.6	25.3
5.500	48.7	5.0	43.7	25.9	20.9	22.8	18.5	13.5	30.2
6.000	52.1	5.8	46.3	31.5	25.7	20.6	25.4	19.6	26.7
6.095	53.9	6.0	47.9	33.2	27.2	20.7	26.3	20.3	27.6
6.190	55.2	6.0	49.2	34.0	28.0	21.2	28.2	22.2	27.0
6.285	56.0	6.0	50.0	35.0	29.0	21.0	29.5	23.5	26.5
6.380	56.0	5.9	50.1	42.7	36.8	13.3	37.4	31.5	18.6
Average						15.6	20.0		

Table C58: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 117.58-131.58 hours)

Time (hours)	0.0			123.58			131.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8	6.3	0.4	5.8
1.000	11.4	4.5	6.9	4.5	0.0	6.9	4.5	0.0	6.9
1.500	16.1	4.7	11.4	4.7	0.0	11.4	4.7	0.0	11.4
2.000	20.2	5.0	15.2	5.0	0.0	15.2	5.0	0.0	15.2
2.500	23.8	3.5	20.3	4.6	1.1	19.2	4.5	1.0	19.3
3.000	28.0	4.2	23.8	4.5	0.3	23.5	4.5	0.3	23.5
3.500	32.9	5.2	27.7	6.9	1.7	26.0	6.0	0.8	26.9
4.000	38.2	4.0	34.2	8.2	4.2	30.0	7.0	3.0	31.2
4.500	41.9	4.1	37.8	13.0	8.9	28.9	11.3	7.2	30.6
5.000	44.7	3.8	40.9	17.9	14.1	26.8	16.9	13.1	27.8
5.500	48.7	5.0	43.7	16.5	11.5	32.2	14.6	9.6	34.1
6.000	52.1	5.8	46.3	23.7	17.9	28.4	22.2	16.4	29.9
6.095	53.9	6.0	47.9	24.9	18.9	29.0	23.2	17.2	30.7
6.190	55.2	6.0	49.2	25.8	19.8	29.4	24.3	18.3	30.9
6.285	56.0	6.0	50.0	28.0	22.0	28.0	27.0	21.0	29.0
6.380	56.0	5.9	50.1	39.0	33.1	17.0	39.0	33.1	17.0
Average						21.0	21.8		

Table C59: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 131.58-147.92 hours)

Time (hours)	0.0			141.92			147.92		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8	6.3	0.4	5.8
1.000	11.4	4.5	6.9	4.5	0.0	6.9	4.5	0.0	6.9
1.500	16.1	4.7	11.4	4.7	0.0	11.4	4.7	0.0	11.4
2.000	20.2	5.0	15.2	5.0	0.0	15.2	5.0	0.0	15.2
2.500	23.8	3.5	20.3	4.3	0.8	19.5	3.5	0.0	20.3
3.000	28.0	4.2	23.8	4.2	0.0	23.8	4.2	0.0	23.8
3.500	32.9	5.2	27.7	5.9	0.7	27.0	5.2	0.0	27.7
4.000	38.2	4.0	34.2	6.0	2.0	32.2	5.5	1.5	32.7
4.500	41.9	4.1	37.8	10.1	6.0	31.8	9.5	5.4	32.4
5.000	44.7	3.8	40.9	14.9	11.1	29.8	13.5	9.7	31.2
5.500	48.7	5.0	43.7	12.7	7.7	36.0	12.3	7.3	36.4
6.000	52.1	5.8	46.3	20.3	14.5	31.8	19.7	13.9	32.4
6.095	53.9	6.0	47.9	22.0	16.0	31.9	21.7	15.7	32.2
6.190	55.2	6.0	49.2	23.5	17.5	31.7	23.0	17.0	32.2
6.285	56.0	6.0	50.0	25.2	19.2	30.8	24.6	18.6	31.4
6.380	56.0	5.9	50.1	35.2	29.3	20.8	35.0	29.1	21.0
Average						22.7	23.1		

Table C60: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 147.92-165.92 hours)

Time (hours)	0.0			155.92			165.92		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8	6.3	0.4	5.8
1.000	11.4	4.5	6.9	4.5	0.0	6.9	4.5	0.0	6.9
1.500	16.1	4.7	11.4	4.7	0.0	11.4	4.7	0.0	11.4
2.000	20.2	5.0	15.2	5.0	0.0	15.2	5.0	0.0	15.2
2.500	23.8	3.5	20.3	3.5	0.0	20.3	3.5	0.0	20.3
3.000	28.0	4.2	23.8	4.2	0.0	23.8	4.2	0.0	23.8
3.500	32.9	5.2	27.7	5.2	0.0	27.7	5.2	0.0	27.7
4.000	38.2	4.0	34.2	4.5	0.5	33.7	4.2	0.2	34.0
4.500	41.9	4.1	37.8	8.9	4.8	33.0	8.0	3.9	33.9
5.000	44.7	3.8	40.9	13.0	9.2	31.7	12.2	8.4	32.5
5.500	48.7	5.0	43.7	11.4	6.4	37.3	10.2	5.2	38.5
6.000	52.1	5.8	46.3	19.3	13.5	32.8	18.5	12.7	33.6
6.095	53.9	6.0	47.9	21.0	15.0	32.9	18.4	12.4	35.5
6.190	55.2	6.0	49.2	22.6	16.6	32.6	21.5	15.5	33.7
6.285	56.0	6.0	50.0	24.6	18.6	31.4	23.8	17.8	32.2
6.380	56.0	5.9	50.1	37.0	31.1	19.0	35.5	29.6	20.5
Average						23.3	23.9		

Table C61: Active storage data (Q_w : 2.85 litres/sec; Q_s : 7.3 ml/min shut at 100.58 hours; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 165.92-170.92 hours)

Time (hours)	0.0			170.92		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.5	8.5	0.0	8.5	0.0	0.0
0.500	12.1	5.9	6.2	6.3	0.4	5.8
1.000	11.4	4.5	6.9	4.5	0.0	6.9
1.500	16.1	4.7	11.4	4.7	0.0	11.4
2.000	20.2	5.0	15.2	5.0	0.0	15.2
2.500	23.8	3.5	20.3	3.5	0.0	20.3
3.000	28.0	4.2	23.8	4.2	0.0	23.8
3.500	32.9	5.2	27.7	5.2	0.0	27.7
4.000	38.2	4.0	34.2	4.2	0.2	34.0
4.500	41.9	4.1	37.8	7.9	3.8	34.0
5.000	44.7	3.8	40.9	11.9	8.1	32.8
5.500	48.7	5.0	43.7	9.5	4.5	39.2
6.000	52.1	5.8	46.3	18.4	12.6	33.7
6.095	53.9	6.0	47.9	19.0	13.0	34.9
6.190	55.2	6.0	49.2	21.2	15.2	34.0
6.285	56.0	6.0	50.0	23.2	17.2	32.8
6.380	56.0	5.9	50.1	34.3	28.4	21.7
Average						24.0

APPENDIX D: Stepped discharge hydrographs scour dataTable D1: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	13.2	7.3	-0.1	12.7	6.8	0.4
1.000	14.9	4.5	10.4	15.3	10.8	-0.4	14.9	10.4	0.0
1.500	17.5	4.7	12.8	17.9	13.2	-0.4	17.0	12.3	0.5
2.000	22.5	5.0	17.5	22.0	17.0	0.5	21.7	16.7	0.8
2.500	27.5	3.5	24.0	27.0	23.5	0.5	24.7	21.2	2.8
3.000	28.7	4.2	24.5	29.0	24.8	-0.3	27.3	23.1	1.4
3.500	34.0	5.2	28.8	32.0	26.8	2.0	30.5	25.3	3.5
4.000	38.4	4.0	34.4	35.2	31.2	3.2	34.0	30.0	4.4
4.500	43.0	4.1	38.9	39.1	35.0	3.9	37.5	33.4	5.5
5.000	46.4	3.8	42.6	42.5	38.7	3.9	41.2	37.4	5.2
5.500	50.3	5.0	45.3	41.8	36.8	8.5	41.7	36.7	8.6
6.000	53.7	5.8	47.9	49.0	43.2	4.7	43.3	37.5	10.4
6.095	55.6	6.0	49.6	47.0	41.0	8.6	46.2	40.2	9.4
6.190	56.5	6.0	50.5	47.7	41.7	8.8	46.9	40.9	9.6
6.285	56.5	6.0	50.5	48.9	42.9	7.6	48.3	42.3	8.2
6.380	56.5	5.9	50.6	47.0	41.1	9.5	46.5	40.6	10.0
	Average					3.6	4.7		

Table D2: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	11.9	6.0	1.2	12.0	6.1	1.1
1.000	14.9	4.5	10.4	15.3	10.8	-0.4	16.0	11.5	-1.1
1.500	17.5	4.7	12.8	17.0	12.3	0.5	17.3	12.6	0.2
2.000	22.5	5.0	17.5	21.8	16.8	0.7	21.0	16.0	1.5
2.500	27.5	3.5	24.0	25.4	21.9	2.1	25.8	22.3	1.7
3.000	28.7	4.2	24.5	26.5	22.3	2.2	25.5	21.3	3.2
3.500	34.0	5.2	28.8	30.2	25.0	3.8	29.8	24.6	4.2
4.000	38.4	4.0	34.4	32.9	28.9	5.5	32.9	28.9	5.5
4.500	43.0	4.1	38.9	36.5	32.4	6.5	35.9	31.8	7.1
5.000	46.4	3.8	42.6	41.9	38.1	4.5	41.0	37.2	5.4
5.500	50.3	5.0	45.3	40.5	35.5	9.8	37.5	32.5	12.8
6.000	53.7	5.8	47.9	43.6	37.8	10.1	44.6	38.8	9.1
6.095	55.6	6.0	49.6	45.4	39.4	10.2	44.8	38.8	10.8
6.190	56.5	6.0	50.5	44.0	38.0	12.5	46.4	40.4	10.1
6.285	56.5	6.0	50.5	45.9	39.9	10.6	47.7	41.7	8.8
6.380	56.5	5.9	50.6	49.3	43.4	7.2	48.9	43.0	7.6
	Average					5.1	5.2		

Table D3: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4 hours)

Time (hours)	0.0			3.0			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	12.3	6.4	0.8	11.3	5.4	1.8
1.000	14.9	4.5	10.4	15.9	11.4	-1.0	16.0	11.5	-1.1
1.500	17.5	4.7	12.8	17.4	12.7	0.1	17.9	13.2	-0.4
2.000	22.5	5.0	17.5	20.7	15.7	1.8	20.4	15.4	2.1
2.500	27.5	3.5	24.0	24.9	21.4	2.6	24.3	20.8	3.2
3.000	28.7	4.2	24.5	25.9	21.7	2.8	24.8	20.6	3.9
3.500	34.0	5.2	28.8	29.2	24.0	4.8	27.7	22.5	6.3
4.000	38.4	4.0	34.4	31.5	27.5	6.9	30.2	26.2	8.2
4.500	43.0	4.1	38.9	35.4	31.3	7.6	33.2	29.1	9.8
5.000	46.4	3.8	42.6	40.0	36.2	6.4	38.2	34.4	8.2
5.500	50.3	5.0	45.3	38.3	33.3	12.0	35.4	30.4	14.9
6.000	53.7	5.8	47.9	41.5	35.7	12.2	40.7	34.9	13.0
6.095	55.6	6.0	49.6	42.3	36.3	13.3	42.9	36.9	12.7
6.190	56.5	6.0	50.5	43.3	37.3	13.2	42.9	36.9	13.6
6.285	56.5	6.0	50.5	44.0	38.0	12.5	44.6	38.6	11.9
6.380	56.5	5.9	50.6	48.5	42.6	8.0	47.6	41.7	8.9
				Average			6.1		
							6.9		

Table D4: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec ends and 3.3 litres/sec starts at 5.08 hours; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4-5.58 hours)

Time (hours)	0.0			5.08			5.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	10.1	4.2	3.0	6.2	0.3	6.9
1.000	14.9	4.5	10.4	14.9	10.4	0.0	8.4	3.9	6.5
1.500	17.5	4.7	12.8	18.0	13.3	-0.5	15.8	11.1	1.7
2.000	22.5	5.0	17.5	18.5	13.5	4.0	19.0	14.0	3.5
2.500	27.5	3.5	24.0	24.2	20.7	3.3	28.2	24.7	-0.7
3.000	28.7	4.2	24.5	22.6	18.4	6.1	15.0	10.8	13.7
3.500	34.0	5.2	28.8	24.0	18.8	10.0	24.7	19.5	9.3
4.000	38.4	4.0	34.4	27.3	23.3	11.1	20.3	16.3	18.1
4.500	43.0	4.1	38.9	33.5	29.4	9.5	31.9	27.8	11.1
5.000	46.4	3.8	42.6	36.6	32.8	9.8	34.0	30.2	12.4
5.500	50.3	5.0	45.3	33.3	28.3	17.0	23.7	18.7	26.6
6.000	53.7	5.8	47.9	37.8	32.0	15.9	35.3	29.5	18.4
6.095	55.6	6.0	49.6	42.8	36.8	12.8	38.7	32.7	16.9
6.190	56.5	6.0	50.5	41.8	35.8	14.7	40.7	34.7	15.8
6.285	56.5	6.0	50.5	42.5	36.5	14.0	42.0	36.0	14.5
6.380	56.5	5.9	50.6	47.7	41.8	8.8	44.0	38.1	12.5
				Average			8.2		
							11.0		

Table D5: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 5.58-6.58 hours)

Time (hours)	0.0			6.08			6.58		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	6.4	1.9	8.5	6.1	1.6	8.8
1.500	17.5	4.7	12.8	11.7	7.0	5.8	11.2	6.5	6.3
2.000	22.5	5.0	17.5	16.8	11.8	5.7	15.4	10.4	7.1
2.500	27.5	3.5	24.0	24.8	21.3	2.7	23.5	20.0	4.0
3.000	28.7	4.2	24.5	20.6	16.4	8.1	19.2	15.0	9.5
3.500	34.0	5.2	28.8	24.7	19.5	9.3	24.3	19.1	9.7
4.000	38.4	4.0	34.4	22.3	18.3	16.1	22.4	18.4	16.0
4.500	43.0	4.1	38.9	30.5	26.4	12.5	28.1	24.0	14.9
5.000	46.4	3.8	42.6	29.9	26.1	16.5	30.0	26.2	16.4
5.500	50.3	5.0	45.3	30.2	25.2	20.1	30.1	25.1	20.2
6.000	53.7	5.8	47.9	32.0	26.2	21.7	31.3	25.5	22.4
6.095	55.6	6.0	49.6	34.6	28.6	21.0	34.2	28.2	21.4
6.190	56.5	6.0	50.5	37.0	31.0	19.5	36.7	30.7	19.8
6.285	56.5	6.0	50.5	38.6	32.6	17.9	38.3	32.3	18.2
6.380	56.5	5.9	50.6	43.8	37.9	12.7	44.1	38.2	12.4
				Average		12.1			12.6

Table D6: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6.58-8.08 hours)

Time (hours)	0.0			7.08			8.08		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	10.0	5.3	7.5	7.3	2.6	10.2
2.000	22.5	5.0	17.5	13.9	8.9	8.6	9.7	4.7	12.8
2.500	27.5	3.5	24.0	21.8	18.3	5.7	16.0	12.5	11.5
3.000	28.7	4.2	24.5	17.0	12.8	11.7	14.0	9.8	14.7
3.500	34.0	5.2	28.8	24.6	19.4	9.4	21.9	16.7	12.1
4.000	38.4	4.0	34.4	22.6	18.6	15.8	23.4	19.4	15.0
4.500	43.0	4.1	38.9	20.9	16.8	22.1	26.0	21.9	17.0
5.000	46.4	3.8	42.6	30.9	27.1	15.5	33.2	29.4	13.2
5.500	50.3	5.0	45.3	31.0	26.0	19.3	26.5	21.5	23.8
6.000	53.7	5.8	47.9	30.9	25.1	22.8	29.9	24.1	23.8
6.095	55.6	6.0	49.6	33.9	27.9	21.7	30.7	24.7	24.9
6.190	56.5	6.0	50.5	34.5	28.5	22.0	31.6	25.6	24.9
6.285	56.5	6.0	50.5	37.9	31.9	18.6	33.0	27.0	23.5
6.380	56.5	5.9	50.6	44.2	38.3	12.3	43.6	37.7	12.9
				Average		13.6			15.2

Table D7: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8.08-10.16 hours)

Time (hours)	0.0			9.16			10.16		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	5.9	1.2	11.6	4.7	0.0	12.8
2.000	22.5	5.0	17.5	6.8	1.8	15.7	6.4	1.4	16.1
2.500	27.5	3.5	24.0	12.4	8.9	15.1	9.8	6.3	17.7
3.000	28.7	4.2	24.5	11.2	7.0	17.5	9.0	4.8	19.7
3.500	34.0	5.2	28.8	17.9	12.7	16.1	14.9	9.7	19.1
4.000	38.4	4.0	34.4	23.6	19.6	14.8	21.2	17.2	17.2
4.500	43.0	4.1	38.9	26.0	21.9	17.0	26.7	22.6	16.3
5.000	46.4	3.8	42.6	33.3	29.5	13.1	30.9	27.1	15.5
5.500	50.3	5.0	45.3	28.7	23.7	21.6	25.5	20.5	24.8
6.000	53.7	5.8	47.9	29.6	23.8	24.1	31.4	25.6	22.3
6.095	55.6	6.0	49.6	32.2	26.2	23.4	31.2	25.2	24.4
6.190	56.5	6.0	50.5	32.9	26.9	23.6	32.8	26.8	23.7
6.285	56.5	6.0	50.5	32.8	26.8	23.7	35.3	29.3	21.2
6.380	56.5	5.9	50.6	43.5	37.6	13.0	39.0	33.1	17.5
Average						15.8	16.8		

Table D8: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 10.16-12.66 hours)

Time (hours)	0.0			11.16			12.66		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	4.7	0.0	12.8	4.7	0.0	12.8
2.000	22.5	5.0	17.5	5.8	0.8	16.7	5.4	0.4	17.1
2.500	27.5	3.5	24.0	8.3	4.8	19.2	6.4	2.9	21.1
3.000	28.7	4.2	24.5	6.2	2.0	22.5	5.0	0.8	23.7
3.500	34.0	5.2	28.8	12.8	7.6	21.2	8.9	3.7	25.1
4.000	38.4	4.0	34.4	17.8	13.8	20.6	14.0	10.0	24.4
4.500	43.0	4.1	38.9	23.8	19.7	19.2	20.0	15.9	23.0
5.000	46.4	3.8	42.6	30.5	26.7	15.9	26.4	22.6	20.0
5.500	50.3	5.0	45.3	24.0	19.0	26.3	25.3	20.3	25.0
6.000	53.7	5.8	47.9	33.0	27.2	20.7	31.4	25.6	22.3
6.095	55.6	6.0	49.6	36.2	30.2	19.4	34.5	28.5	21.1
6.190	56.5	6.0	50.5	30.2	24.2	26.3	35.1	29.1	21.4
6.285	56.5	6.0	50.5	32.7	26.7	23.8	32.3	26.3	24.2
6.380	56.5	5.9	50.6	40.6	34.7	15.9	41.4	35.5	15.1
Average						17.5	18.5		

Table D9: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 12.66-14.66 hours)

Time (hours)	0.0			13.66			14.66		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	4.7	0.0	12.8	4.7	0.0	12.8
2.000	22.5	5.0	17.5	5.4	0.4	17.1	5.4	0.4	17.1
2.500	27.5	3.5	24.0	6.4	2.9	21.1	6.4	2.9	21.1
3.000	28.7	4.2	24.5	5.0	0.8	23.7	5.0	0.8	23.7
3.500	34.0	5.2	28.8	8.9	3.7	25.1	8.9	3.7	25.1
4.000	38.4	4.0	34.4	14.0	10.0	24.4	14.0	10.0	24.4
4.500	43.0	4.1	38.9	20.0	15.9	23.0	20.0	15.9	23.0
5.000	46.4	3.8	42.6	26.4	22.6	20.0	26.4	22.6	20.0
5.500	50.3	5.0	45.3	25.3	20.3	25.0	25.3	20.3	25.0
6.000	53.7	5.8	47.9	31.4	25.6	22.3	31.4	25.6	22.3
6.095	55.6	6.0	49.6	34.5	28.5	21.1	34.5	28.5	21.1
6.190	56.5	6.0	50.5	35.1	29.1	21.4	35.1	29.1	21.4
6.285	56.5	6.0	50.5	32.3	26.3	24.2	32.3	26.3	24.2
6.380	56.5	5.9	50.6	41.4	35.5	15.1	41.4	35.5	15.1
Average						18.5	18.5		

Table D10: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 14.66-16.66 hours)

Time (hours)	0.0			15.66			16.66		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	4.7	0.0	12.8	4.7	0.0	12.8
2.000	22.5	5.0	17.5	5.4	0.4	17.1	5.4	0.4	17.1
2.500	27.5	3.5	24.0	6.4	2.9	21.1	6.4	2.9	21.1
3.000	28.7	4.2	24.5	5.0	0.8	23.7	5.0	0.8	23.7
3.500	34.0	5.2	28.8	8.9	3.7	25.1	8.9	3.7	25.1
4.000	38.4	4.0	34.4	14.0	10.0	24.4	14.0	10.0	24.4
4.500	43.0	4.1	38.9	20.0	15.9	23.0	20.0	15.9	23.0
5.000	46.4	3.8	42.6	26.4	22.6	20.0	26.4	22.6	20.0
5.500	50.3	5.0	45.3	25.3	20.3	25.0	25.3	20.3	25.0
6.000	53.7	5.8	47.9	31.4	25.6	22.3	31.4	25.6	22.3
6.095	55.6	6.0	49.6	34.5	28.5	21.1	34.5	28.5	21.1
6.190	56.5	6.0	50.5	35.1	29.1	21.4	35.1	29.1	21.4
6.285	56.5	6.0	50.5	32.3	26.3	24.2	32.3	26.3	24.2
6.380	56.5	5.9	50.6	41.4	35.5	15.1	41.4	35.5	15.1
Average						18.5	18.5		

Table D11: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 16.66-17.66 hours)

Time (hours)	0.0			17.66		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0
0.500	13.1	5.9	7.2	5.9	0.0	7.2
1.000	14.9	4.5	10.4	4.5	0.0	10.4
1.500	17.5	4.7	12.8	4.7	0.0	12.8
2.000	22.5	5.0	17.5	5.4	0.4	17.1
2.500	27.5	3.5	24.0	6.4	2.9	21.1
3.000	28.7	4.2	24.5	5.0	0.8	23.7
3.500	34.0	5.2	28.8	8.9	3.7	25.1
4.000	38.4	4.0	34.4	14.0	10.0	24.4
4.500	43.0	4.1	38.9	20.0	15.9	23.0
5.000	46.4	3.8	42.6	26.4	22.6	20.0
5.500	50.3	5.0	45.3	25.3	20.3	25.0
6.000	53.7	5.8	47.9	31.4	25.6	22.3
6.095	55.6	6.0	49.6	34.5	28.5	21.1
6.190	56.5	6.0	50.5	35.1	29.1	21.4
6.285	56.5	6.0	50.5	32.3	26.3	24.2
6.380	56.5	5.9	50.6	41.4	35.5	15.1
				Average		18.5

Table D12: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	10.4	1.6	-1.6	13.2	4.4	-4.4
0.500	11.6	5.9	5.7	11.4	5.5	0.2	11.7	5.8	-0.1
1.000	14.4	4.5	9.9	13.9	9.4	0.5	14.5	10.0	-0.1
1.500	18.0	4.7	13.3	18.0	13.3	0.0	18.0	13.3	0.0
2.000	20.5	5.0	15.5	20.2	15.2	0.3	20.5	15.5	0.0
2.500	25.3	3.5	21.8	25.5	22.0	-0.2	25.2	21.7	0.1
3.000	28.7	4.2	24.5	28.5	24.3	0.2	26.9	22.7	1.8
3.500	33.7	5.2	28.5	33.4	28.2	0.3	31.0	25.8	2.7
4.000	38.5	4.0	34.5	36.5	32.5	2.0	34.6	30.6	3.9
4.500	43.2	4.1	39.1	39.6	35.5	3.6	39.0	34.9	4.2
5.000	46.0	3.8	42.2	44.0	40.2	2.0	42.9	39.1	3.1
5.500	47.2	5.0	42.2	43.1	38.1	4.1	39.6	34.6	7.6
6.000	52.2	5.8	46.4	49.0	43.2	3.2	46.0	40.2	6.2
6.095	53.9	6.0	47.9	46.5	40.5	7.4	48.0	42.0	5.9
6.190	55.5	6.0	49.5	49.5	43.5	6.0	46.0	40.0	9.5
6.285	56.0	6.0	50.0	48.1	42.1	7.9	45.5	39.5	10.5
6.380	57.2	5.9	51.3	49.9	44.0	7.3	49.0	43.1	8.2
				Average		2.5	3.5		

Table D13: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	12.0	3.2	-3.2	12.0	3.2	-3.2
0.500	11.6	5.9	5.7	11.6	5.7	0.0	15.9	10.0	-4.3
1.000	14.4	4.5	9.9	14.3	9.8	0.1	14.3	9.8	0.1
1.500	18.0	4.7	13.3	17.9	13.2	0.1	17.7	13.0	0.3
2.000	20.5	5.0	15.5	20.5	15.5	0.0	20.5	15.5	0.0
2.500	25.3	3.5	21.8	25.0	21.5	0.3	24.4	20.9	0.9
3.000	28.7	4.2	24.5	25.4	21.2	3.3	24.9	20.7	3.8
3.500	33.7	5.2	28.5	29.9	24.7	3.8	29.0	23.8	4.7
4.000	38.5	4.0	34.5	32.4	28.4	6.1	31.6	27.6	6.9
4.500	43.2	4.1	39.1	37.0	32.9	6.2	36.6	32.5	6.6
5.000	46.0	3.8	42.2	40.3	36.5	5.7	40.2	36.4	5.8
5.500	47.2	5.0	42.2	41.0	36.0	6.2	40.5	35.5	6.7
6.000	52.2	5.8	46.4	42.3	36.5	9.9	42.0	36.2	10.2
6.095	53.9	6.0	47.9	45.1	39.1	8.8	44.4	38.4	9.5
6.190	55.5	6.0	49.5	46.8	40.8	8.7	45.5	39.5	10.0
6.285	56.0	6.0	50.0	47.0	41.0	9.0	46.9	40.9	9.1
6.380	57.2	5.9	51.3	48.1	42.2	9.1	47.9	42.0	9.3
Average						4.4	4.5		

Table D14: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 2-4.27 hours)

Time (hours)	0.0			3.27			4.27		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	10.4	1.6	-1.6	10.3	1.5	-1.5
0.500	11.6	5.9	5.7	16.7	10.8	-5.1	16.1	10.2	-4.5
1.000	14.4	4.5	9.9	14.4	9.9	0.0	14.0	9.5	0.4
1.500	18.0	4.7	13.3	17.8	13.1	0.2	17.2	12.5	0.8
2.000	20.5	5.0	15.5	20.1	15.1	0.4	19.8	14.8	0.7
2.500	25.3	3.5	21.8	23.5	20.0	1.8	23.1	19.6	2.2
3.000	28.7	4.2	24.5	24.2	20.0	4.5	23.3	19.1	5.4
3.500	33.7	5.2	28.5	27.5	22.3	6.2	27.6	22.4	6.1
4.000	38.5	4.0	34.5	28.8	24.8	9.7	28.4	24.4	10.1
4.500	43.2	4.1	39.1	33.3	29.2	9.9	33.0	28.9	10.2
5.000	46.0	3.8	42.2	37.4	33.6	8.6	36.9	33.1	9.1
5.500	47.2	5.0	42.2	36.8	31.8	10.4	35.9	30.9	11.3
6.000	52.2	5.8	46.4	39.4	33.6	12.8	41.2	35.4	11.0
6.095	53.9	6.0	47.9	40.4	34.4	13.5	42.8	36.8	11.1
6.190	55.5	6.0	49.5	42.0	36.0	13.5	41.8	35.8	13.7
6.285	56.0	6.0	50.0	44.5	38.5	11.5	40.0	34.0	16.0
6.380	57.2	5.9	51.3	47.9	42.0	9.3	46.0	40.1	11.2
Average						6.2	6.7		

Table D15: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec ends and 3.3 litres/sec starts at 5.93 hours; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 4.27-6.43 hours)

Time (hours)	0.0			5.93			6.43		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	10.3	1.5	-1.5	8.8	0.0	0.0
0.500	11.6	5.9	5.7	16.1	10.2	-4.5	8.9	3.0	2.7
1.000	14.4	4.5	9.9	18.9	14.4	-4.5	16.9	12.4	-2.5
1.500	18.0	4.7	13.3	17.1	12.4	0.9	20.8	16.1	-2.8
2.000	20.5	5.0	15.5	19.5	14.5	1.0	21.4	16.4	-0.9
2.500	25.3	3.5	21.8	22.8	19.3	2.5	19.8	16.3	5.5
3.000	28.7	4.2	24.5	23.0	18.8	5.7	19.3	15.1	9.4
3.500	33.7	5.2	28.5	26.6	21.4	7.1	25.3	20.1	8.4
4.000	38.5	4.0	34.5	27.4	23.4	11.1	26.3	22.3	12.2
4.500	43.2	4.1	39.1	31.0	26.9	12.2	28.4	24.3	14.8
5.000	46.0	3.8	42.2	35.7	31.9	10.3	33.6	29.8	12.4
5.500	47.2	5.0	42.2	34.6	29.6	12.6	33.8	28.8	13.4
6.000	52.2	5.8	46.4	40.9	35.1	11.3	36.2	30.4	16.0
6.095	53.9	6.0	47.9	42.2	36.2	11.7	37.5	31.5	16.4
6.190	55.5	6.0	49.5	40.1	34.1	15.4	37.0	31.0	18.5
6.285	56.0	6.0	50.0	39.6	33.6	16.4	39.0	33.0	17.0
6.380	57.2	5.9	51.3	43.2	37.3	14.0	40.9	35.0	16.3
Average						7.2	9.2		

Table D16: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 6.43-7.43 hours)

Time (hours)	0.0			6.93			7.43		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	6.2	0.3	5.4	6.3	0.4	5.3
1.000	14.4	4.5	9.9	11.3	6.8	3.1	9.0	4.5	5.4
1.500	18.0	4.7	13.3	20.1	15.4	-2.1	15.2	10.5	2.8
2.000	20.5	5.0	15.5	21.3	16.3	-0.8	18.2	13.2	2.3
2.500	25.3	3.5	21.8	27.8	24.3	-2.5	23.4	19.9	1.9
3.000	28.7	4.2	24.5	27.5	23.3	1.2	19.9	15.7	8.8
3.500	33.7	5.2	28.5	23.0	17.8	10.7	25.5	20.3	8.2
4.000	38.5	4.0	34.5	19.7	15.7	18.8	22.5	18.5	16.0
4.500	43.2	4.1	39.1	21.9	17.8	21.3	27.1	23.0	16.1
5.000	46.0	3.8	42.2	35.5	31.7	10.5	30.9	27.1	15.1
5.500	47.2	5.0	42.2	27.5	22.5	19.7	26.8	21.8	20.4
6.000	52.2	5.8	46.4	30.5	24.7	21.7	31.5	25.7	20.7
6.095	53.9	6.0	47.9	33.9	27.9	20.0	34.5	28.5	19.4
6.190	55.5	6.0	49.5	35.5	29.5	20.0	34.6	28.6	20.9
6.285	56.0	6.0	50.0	38.8	32.8	17.2	37.3	31.3	18.7
6.380	57.2	5.9	51.3	44.9	39.0	12.3	43.3	37.4	13.9
Average						10.4	11.5		

Table D17: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 7.43-8.93 hours)

Time (hours)	0.0			7.93			8.93		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	6.0	0.1	5.6	5.9	0.0	5.7
1.000	14.4	4.5	9.9	6.0	1.5	8.4	5.8	1.3	8.6
1.500	18.0	4.7	13.3	9.8	5.1	8.2	9.6	4.9	8.4
2.000	20.5	5.0	15.5	12.4	7.4	8.1	12.3	7.3	8.2
2.500	25.3	3.5	21.8	19.7	16.2	5.6	19.5	16.0	5.8
3.000	28.7	4.2	24.5	15.6	11.4	13.1	15.4	11.2	13.3
3.500	33.7	5.2	28.5	24.2	19.0	9.5	22.7	17.5	11.0
4.000	38.5	4.0	34.5	27.0	23.0	11.5	26.5	22.5	12.0
4.500	43.2	4.1	39.1	29.0	24.9	14.2	27.3	23.2	15.9
5.000	46.0	3.8	42.2	32.8	29.0	13.2	28.6	24.8	17.4
5.500	47.2	5.0	42.2	28.0	23.0	19.2	27.8	22.8	19.4
6.000	52.2	5.8	46.4	36.4	30.6	15.8	35.2	29.4	17.0
6.095	53.9	6.0	47.9	31.9	25.9	22.0	30.9	24.9	23.0
6.190	55.5	6.0	49.5	34.0	28.0	21.5	32.8	26.8	22.7
6.285	56.0	6.0	50.0	38.0	32.0	18.0	35.3	29.3	20.7
6.380	57.2	5.9	51.3	45.5	39.6	11.7	43.5	37.6	13.7
Average						12.1	13.1		

Table D18: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 8.93-10.93 hours)

Time (hours)	0.0			9.93			10.93		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	5.9	0.0	5.7	5.9	0.0	5.7
1.000	14.4	4.5	9.9	5.4	0.9	9.0	5.0	0.5	9.4
1.500	18.0	4.7	13.3	9.2	4.5	8.8	8.0	3.3	10.0
2.000	20.5	5.0	15.5	12.0	7.0	8.5	9.6	4.6	10.9
2.500	25.3	3.5	21.8	16.3	12.8	9.0	14.2	10.7	11.1
3.000	28.7	4.2	24.5	15.5	11.3	13.2	14.2	10.0	14.5
3.500	33.7	5.2	28.5	20.6	15.4	13.1	17.2	12.0	16.5
4.000	38.5	4.0	34.5	24.3	20.3	14.2	21.5	17.5	17.0
4.500	43.2	4.1	39.1	24.8	20.7	18.4	24.5	20.4	18.7
5.000	46.0	3.8	42.2	27.9	24.1	18.1	26.0	22.2	20.0
5.500	47.2	5.0	42.2	27.9	22.9	19.3	25.0	20.0	22.2
6.000	52.2	5.8	46.4	34.7	28.9	17.5	35.5	29.7	16.7
6.095	53.9	6.0	47.9	35.5	29.5	18.4	30.5	24.5	23.4
6.190	55.5	6.0	49.5	31.4	25.4	24.1	31.8	25.8	23.7
6.285	56.0	6.0	50.0	33.4	27.4	22.6	33.3	27.3	22.7
6.380	57.2	5.9	51.3	41.9	36.0	15.3	42.7	36.8	14.5
Average						13.8	15.1		

Table D19: Stepped discharge hydrographs scour data (Q_w : 3.3 litres/sec; Q_s : 1.8 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 10.93-13.27 hours)

Time (hours)	0.0			11.93			13.27		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	5.9	0.0	5.7	5.9	0.0	5.7
1.000	14.4	4.5	9.9	5.0	0.5	9.4	4.7	0.2	9.7
1.500	18.0	4.7	13.3	7.0	2.3	11.0	7.2	2.5	10.8
2.000	20.5	5.0	15.5	8.5	3.5	12.0	8.3	3.3	12.2
2.500	25.3	3.5	21.8	13.3	9.8	12.0	11.6	8.1	13.7
3.000	28.7	4.2	24.5	13.0	8.8	15.7	10.9	6.7	17.8
3.500	33.7	5.2	28.5	16.0	10.8	17.7	16.0	10.8	17.7
4.000	38.5	4.0	34.5	17.8	13.8	20.7	19.5	15.5	19.0
4.500	43.2	4.1	39.1	26.0	21.9	17.2	20.2	16.1	23.0
5.000	46.0	3.8	42.2	27.5	23.7	18.5	30.6	26.8	15.4
5.500	47.2	5.0	42.2	24.2	19.2	23.0	21.2	16.2	26.0
6.000	52.2	5.8	46.4	29.5	23.7	22.7	32.8	27.0	19.4
6.095	53.9	6.0	47.9	31.9	25.9	22.0	29.6	23.6	24.3
6.190	55.5	6.0	49.5	34.0	28.0	21.5	30.5	24.5	25.0
6.285	56.0	6.0	50.0	34.2	28.2	21.8	32.0	26.0	24.0
6.380	57.2	5.9	51.3	39.9	34.0	17.3	41.7	35.8	15.5
Average						15.8	16.4		

Table D20: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 13.27-29.27 hours)

Time (hours)	0.0			20.27			29.27		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	5.9	0.0	5.7	5.9	0.0	5.7
1.000	14.4	4.5	9.9	4.7	0.2	9.7	4.7	0.2	9.7
1.500	18.0	4.7	13.3	7.2	2.5	10.8	7.2	2.5	10.8
2.000	20.5	5.0	15.5	8.3	3.3	12.2	8.3	3.3	12.2
2.500	25.3	3.5	21.8	11.6	8.1	13.7	11.6	8.1	13.7
3.000	28.7	4.2	24.5	10.9	6.7	17.8	10.9	6.7	17.8
3.500	33.7	5.2	28.5	16.0	10.8	17.7	16.0	10.8	17.7
4.000	38.5	4.0	34.5	19.5	15.5	19.0	19.5	15.5	19.0
4.500	43.2	4.1	39.1	20.2	16.1	23.0	20.2	16.1	23.0
5.000	46.0	3.8	42.2	30.6	26.8	15.4	30.6	26.8	15.4
5.500	47.2	5.0	42.2	21.2	16.2	26.0	21.2	16.2	26.0
6.000	52.2	5.8	46.4	32.8	27.0	19.4	32.8	27.0	19.4
6.095	53.9	6.0	47.9	29.6	23.6	24.3	29.6	23.6	24.3
6.190	55.5	6.0	49.5	30.5	24.5	25.0	30.5	24.5	25.0
6.285	56.0	6.0	50.0	32.0	26.0	24.0	32.0	26.0	24.0
6.380	57.2	5.9	51.3	41.7	35.8	15.5	41.7	35.8	15.5
Average						16.4	16.4		

Table D21: Stepped discharge hydrographs scour data (Q_w : 1.73 litres/sec; Q_s : 0.00 ml/min; D_{50} : 0.775 mm; b: 100 mm; Measuring times range: 29.27-34.52 hours)

Time (hours)	0.0			34.52		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	8.8	8.8	0.0	8.8	0.0	0.0
0.500	11.6	5.9	5.7	5.9	0.0	5.7
1.000	14.4	4.5	9.9	4.7	0.2	9.7
1.500	18.0	4.7	13.3	7.2	2.5	10.8
2.000	20.5	5.0	15.5	8.3	3.3	12.2
2.500	25.3	3.5	21.8	11.6	8.1	13.7
3.000	28.7	4.2	24.5	10.9	6.7	17.8
3.500	33.7	5.2	28.5	16.0	10.8	17.7
4.000	38.5	4.0	34.5	19.5	15.5	19.0
4.500	43.2	4.1	39.1	20.2	16.1	23.0
5.000	46.0	3.8	42.2	30.6	26.8	15.4
5.500	47.2	5.0	42.2	21.2	16.2	26.0
6.000	52.2	5.8	46.4	32.8	27.0	19.4
6.095	53.9	6.0	47.9	29.6	23.6	24.3
6.190	55.5	6.0	49.5	30.5	24.5	25.0
6.285	56.0	6.0	50.0	32.0	26.0	24.0
6.380	57.2	5.9	51.3	41.7	35.8	15.5
				Average		16.4

APPENDIX E: Experimental data on movement of sediment in a series of poolsTable E1: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	14.0	11.0	0.3	13.5	10.5	0.8
1.000	23.9	2.4	21.5	21.1	18.7	2.8	19.6	17.2	4.3
1.500	37.5	2.5	35.0	27.0	24.5	10.5	23.2	20.7	14.3
2.000	46.5	2.5	44.0	34.8	32.3	11.7	30.0	27.5	16.5
2.250	48.2	1.4	46.8	38.5	37.1	9.7	34.0	32.6	14.2
2.500	54.6	0.9	53.7	44.9	44.0	9.7	42.0	41.1	12.6
Average						6.4	9.0		

Table E2: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	13.2	10.2	1.1	12.8	9.8	1.5
1.000	23.9	2.4	21.5	18.0	15.6	5.9	17.0	14.6	6.9
1.500	37.5	2.5	35.0	21.0	18.5	16.5	19.8	17.3	17.7
2.000	46.5	2.5	44.0	28.2	25.7	18.3	26.8	24.3	19.7
2.250	48.2	1.4	46.8	31.5	30.1	16.7	30.3	28.9	17.9
2.500	54.6	0.9	53.7	41.0	40.1	13.6	39.9	39.0	14.7
Average						10.3	11.2		

Table E3: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0			3			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	12.3	9.3	2.0	12.5	9.5	1.8
1.000	23.9	2.4	21.5	15.5	13.1	8.4	14.3	11.9	9.6
1.500	37.5	2.5	35.0	17.8	15.3	19.7	16.2	13.7	21.3
2.000	46.5	2.5	44.0	22.8	20.3	23.7	22.3	19.8	24.2
2.250	48.2	1.4	46.8	28.0	26.6	20.2	25.7	24.3	22.5
2.500	54.6	0.9	53.7	39.5	38.6	15.1	39.8	38.9	14.8
Average						12.7	13.5		

Table E4: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0			5			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	11.9	8.9	2.4	11.8	8.8	2.5
1.000	23.9	2.4	21.5	13.0	10.6	10.9	12.0	9.6	11.9
1.500	37.5	2.5	35.0	15.0	12.5	22.5	14.0	11.5	23.5
2.000	46.5	2.5	44.0	20.5	18.0	26.0	18.0	15.5	28.5
2.250	48.2	1.4	46.8	24.0	22.6	24.2	23.0	21.6	25.2
2.500	54.6	0.9	53.7	39.0	38.1	15.6	39.6	38.7	15.0
Average						14.5	15.2		

Table E5: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)

Time (hours)	0.0			7			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	11.6	8.6	2.7	10.5	7.5	3.8
1.000	23.9	2.4	21.5	11.0	8.6	12.9	10.3	7.9	13.6
1.500	37.5	2.5	35.0	13.5	11.0	24.0	12.2	9.7	25.3
2.000	46.5	2.5	44.0	18.5	16.0	28.0	17.3	14.8	29.2
2.250	48.2	1.4	46.8	22.5	21.1	25.7	21.5	20.1	26.7
2.500	54.6	0.9	53.7	39.4	38.5	15.2	38.0	37.1	16.6
Average						15.5	16.5		

Table E6: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0			10			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	10.4	7.4	3.9	10.1	7.1	4.2
1.000	23.9	2.4	21.5	9.8	7.4	14.1	9.0	6.6	14.9
1.500	37.5	2.5	35.0	12.0	9.5	25.5	11.3	8.8	26.2
2.000	46.5	2.5	44.0	16.9	14.4	29.6	15.8	13.3	30.7
2.250	48.2	1.4	46.8	20.7	19.3	27.5	20.0	18.6	28.2
2.500	54.6	0.9	53.7	38.0	37.1	16.6	37.5	36.6	17.1
Average						16.7	17.3		

Table E7: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-23 hours)

Time (hours)	0.0			14			23.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	9.4	6.4	4.9	8.7	5.7	5.6
1.000	23.9	2.4	21.5	8.0	5.6	15.9	5.6	3.2	18.3
1.500	37.5	2.5	35.0	10.4	7.9	27.1	7.8	5.3	29.7
2.000	46.5	2.5	44.0	14.5	12.0	32.0	12.5	10.0	34.0
2.250	48.2	1.4	46.8	18.9	17.5	29.3	16.4	15.0	31.8
2.500	54.6	0.9	53.7	35.8	34.9	18.8	38.2	37.3	16.4
Average						18.3	19.4		

Table E8: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 23-37 hours)

Time (hours)	0.0			30			37.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	7.7	4.7	6.6	6.5	3.5	7.8
1.000	23.9	2.4	21.5	5.0	2.6	18.9	4.8	2.4	19.1
1.500	37.5	2.5	35.0	6.8	4.3	30.7	6.4	3.9	31.1
2.000	46.5	2.5	44.0	11.7	9.2	34.8	10.4	7.9	36.1
2.250	48.2	1.4	46.8	15.5	14.1	32.7	14.3	12.9	33.9
2.500	54.6	0.9	53.7	38.0	37.1	16.6	36.2	35.3	18.4
Average						20.0	20.9		

Table E9: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)

Time (hours)	0.0			49			56.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	6.0	3.0	8.3	6.0	3.0	8.3
1.000	23.9	2.4	21.5	4.0	1.6	19.9	3.4	1.0	20.5
1.500	37.5	2.5	35.0	5.7	3.2	31.8	5.0	2.5	32.5
2.000	46.5	2.5	44.0	9.2	6.7	37.3	8.1	5.6	38.4
2.250	48.2	1.4	46.8	13.7	12.3	34.5	12.3	10.9	35.9
2.500	54.6	0.9	53.7	36.0	35.1	18.6	35.0	34.1	19.6
Average						21.5	22.2		

Table E10: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)

Time (hours)	0.0			62			72.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	6.0	3.0	8.3	6.0	3.0	8.3
1.000	23.9	2.4	21.5	4.0	1.6	19.9	3.8	1.4	20.1
1.500	37.5	2.5	35.0	5.0	2.5	32.5	4.7	2.2	32.8
2.000	46.5	2.5	44.0	7.0	4.5	39.5	7.0	4.5	39.5
2.250	48.2	1.4	46.8	11.5	10.1	36.7	11.3	9.9	36.9
2.500	54.6	0.9	53.7	33.1	32.2	21.5	33.0	32.1	21.6
Average						22.6	22.7		

Table E11: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)

Time (hours)	0.0			80			87.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	5.9	2.9	8.4	5.9	2.9	8.4
1.000	23.9	2.4	21.5	3.9	1.5	20.0	3.8	1.4	20.1
1.500	37.5	2.5	35.0	4.7	2.2	32.8	4.6	2.1	32.9
2.000	46.5	2.5	44.0	6.9	4.4	39.6	7.0	4.5	39.5
2.250	48.2	1.4	46.8	11.4	10.0	36.8	11.4	10.0	36.8
2.500	54.6	0.9	53.7	33.1	32.2	21.5	33.3	32.4	21.3
Average						22.7	22.7		

Table E12: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 87-96 hours)

Time (hours)	0.0			96		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0
0.500	14.3	3.0	11.3	5.7	2.7	8.6
1.000	23.9	2.4	21.5	3.7	1.3	20.2
1.500	37.5	2.5	35.0	4.8	2.3	32.7
2.000	46.5	2.5	44.0	7.0	4.5	39.5
2.250	48.2	1.4	46.8	11.4	10.0	36.8
2.500	54.6	0.9	53.7	33.2	32.3	21.4
Average						22.7

Table E13: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0					0.5			1.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	29.5	27.0	-5.5	22.0	19.5	2.0
1.500	36.9	23.8	1.9	13.1	21.9	24.0	22.1	12.9	43.5	41.6	-6.6
2.000	46.0	35.3	2.0	10.7	33.3	30.9	28.9	15.1	37.0	35.0	9.0
2.250	49.3	39.0	2.5	10.3	36.5	32.7	30.2	16.6	23.8	21.3	25.5
2.500	55.0	41.5	1.3	13.5	40.2	42.5	41.2	12.5	35.5	34.2	19.5
Average				9.8				9.0			8.7

Table E14: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0					1.5			2.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	15.8	13.3	8.2	10.0	7.5	14.0
1.500	36.9	23.8	1.9	13.1	21.9	35.0	33.1	1.9	31.1	29.2	5.8
2.000	46.0	35.3	2.0	10.7	33.3	39.4	37.4	6.6	38.2	36.2	7.8
2.250	49.3	39.0	2.5	10.3	36.5	29.7	27.2	19.6	36.7	34.2	12.6
2.500	55.0	41.5	1.3	13.5	40.2	39.3	38.0	15.7	41.0	39.7	14.0
Average				9.8				9.0			9.4

Table E15: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0					3			4.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	4.9	2.4	19.1	3.4	0.9	20.6
1.500	36.9	23.8	1.9	13.1	21.9	25.0	23.1	11.9	22.8	20.9	14.1
2.000	46.0	35.3	2.0	10.7	33.3	35.5	33.5	10.5	29.0	27.0	17.0
2.250	49.3	39.0	2.5	10.3	36.5	38.7	36.2	10.6	34.4	31.9	14.9
2.500	55.0	41.5	1.3	13.5	40.2	40.0	38.7	15.0	39.1	37.8	15.9
Average				9.8				11.2			13.4

Table E16: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0					5			6.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	3.2	0.7	20.8	3.0	0.5	21.0
1.500	36.9	23.8	1.9	13.1	21.9	19.7	17.8	17.2	20.2	18.3	16.7
2.000	46.0	35.3	2.0	10.7	33.3	26.4	24.4	19.6	24.2	22.2	21.8
2.250	49.3	39.0	2.5	10.3	36.5	31.5	29.0	17.8	28.5	26.0	20.8
2.500	55.0	41.5	1.3	13.5	40.2	39.5	38.2	15.5	38.6	37.3	16.4
Average				9.8				14.6			

Table E17: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)

Time (hours)	0.0					7			8.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	3.2	0.7	20.8	3.2	0.7	20.8
1.500	36.9	23.8	1.9	13.1	21.9	17.5	15.6	19.4	17.0	15.1	19.9
2.000	46.0	35.3	2.0	10.7	33.3	23.4	21.4	22.6	22.3	20.3	23.7
2.250	49.3	39.0	2.5	10.3	36.5	27.2	24.7	22.1	23.9	21.4	25.4
2.500	55.0	41.5	1.3	13.5	40.2	39.8	38.5	15.2	38.9	37.6	16.1
Average				9.8				15.9			

Table E18: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0					10			12.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	3.2	0.7	20.8	3.2	0.7	20.8
1.500	36.9	23.8	1.9	13.1	21.9	14.0	12.1	22.9	13.0	11.1	23.9
2.000	46.0	35.3	2.0	10.7	33.3	20.5	18.5	25.5	19.8	17.8	26.2
2.250	49.3	39.0	2.5	10.3	36.5	24.0	21.5	25.3	23.0	20.5	26.3
2.500	55.0	41.5	1.3	13.5	40.2	38.5	37.2	16.5	38.2	36.9	16.8
Average				9.8				17.5			

Table E19: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-23 hours)

Time (hours)	0.0					14			23.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	3.2	0.7	20.8	3.0	0.5	21.0
1.500	36.9	23.8	1.9	13.1	21.9	11.9	10.0	25.0	8.9	7.0	28.0
2.000	46.0	35.3	2.0	10.7	33.3	19.9	17.9	26.1	16.9	14.9	29.1
2.250	49.3	39.0	2.5	10.3	36.5	22.3	19.8	27.0	19.3	16.8	30.0
2.500	55.0	41.5	1.3	13.5	40.2	38.2	36.9	16.8	37.0	35.7	18.0
Average				9.8				18.1			

Table E20: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 23-37 hours)

Time (hours)	0.0					30			37.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	3.0	0.5	21.0	3.0	0.5	21.0
1.500	36.9	23.8	1.9	13.1	21.9	7.2	5.3	29.7	5.8	3.9	31.1
2.000	46.0	35.3	2.0	10.7	33.3	16.3	14.3	29.7	16.0	14.0	30.0
2.250	49.3	39.0	2.5	10.3	36.5	18.7	16.2	30.6	19.9	17.4	29.4
2.500	55.0	41.5	1.3	13.5	40.2	37.0	35.7	18.0	37.0	35.7	18.0
Average				9.8				20.0			

Table E21: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)

Time (hours)	0.0					49			56.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	2.8	0.3	21.2	2.8	0.3	21.2
1.500	36.9	23.8	1.9	13.1	21.9	5.0	3.1	31.9	4.5	2.6	32.4
2.000	46.0	35.3	2.0	10.7	33.3	15.3	13.3	30.7	14.4	12.4	31.6
2.250	49.3	39.0	2.5	10.3	36.5	17.9	15.4	31.4	17.1	14.6	32.2
2.500	55.0	41.5	1.3	13.5	40.2	36.4	35.1	18.6	37.0	35.7	18.0
Average				9.8				20.7			

Table E22: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)

Time (hours)	0.0					62			72.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	2.8	0.3	21.2	2.8	0.3	21.2
1.500	36.9	23.8	1.9	13.1	21.9	3.9	2.0	33.0	3.4	1.5	33.5
2.000	46.0	35.3	2.0	10.7	33.3	14.5	12.5	31.5	14.6	12.6	31.4
2.250	49.3	39.0	2.5	10.3	36.5	17.3	14.8	32.0	16.5	14.0	32.8
2.500	55.0	41.5	1.3	13.5	40.2	36.2	34.9	18.8	36.8	35.5	18.2
Average				9.8				21.1			21.2

Table E23: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)

Time (hours)	0.0					80			87.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	2.8	0.3	21.2	2.8	0.3	21.2
1.500	36.9	23.8	1.9	13.1	21.9	2.9	1.0	34.0	2.7	0.8	34.2
2.000	46.0	35.3	2.0	10.7	33.3	13.5	11.5	32.5	13.3	11.3	32.7
2.250	49.3	39.0	2.5	10.3	36.5	16.5	14.0	32.8	16.4	13.9	32.9
2.500	55.0	41.5	1.3	13.5	40.2	36.8	35.5	18.2	36.8	35.5	18.2
Average				9.8				21.4			21.5

Table E24: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 87-96 hours)

Time (hours)	0.0					96		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0
0.500	13.1	1.8	1.8	11.3	0.0	1.8	0.0	11.3
1.000	24.0	14.5	2.5	9.5	12.0	2.8	0.3	21.2
1.500	36.9	23.8	1.9	13.1	21.9	2.2	0.3	34.7
2.000	46.0	35.3	2.0	10.7	33.3	13.2	11.2	32.8
2.250	49.3	39.0	2.5	10.3	36.5	15.7	13.2	33.6
2.500	55.0	41.5	1.3	13.5	40.2	37.2	35.9	17.8
Average				9.8				21.6

Table E25: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0					0.5			1.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	14.9	11.9	9.6	27.0	24.0	-2.5
1.500	38.3	25.0	3.3	13.3	21.7	31.4	28.1	6.9	35.8	32.5	2.5
2.000	48.0	35.5	4.0	12.5	31.5	35.4	31.4	12.6	34.4	30.4	13.6
2.250	49.8	38.8	3.0	11	35.8	43.0	40.0	6.8	19.2	16.2	30.6
2.500	56.9	41.9	3.2	15	38.7	38.8	35.6	18.1	34.6	31.4	22.3
Average				10.8				9.3			11.1

Table E26: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0					1.5			2.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	12.9	9.9	11.6	5.5	2.5	19.0
1.500	38.3	25.0	3.3	13.3	21.7	34.2	30.9	4.1	32.8	29.5	5.5
2.000	48.0	35.5	4.0	12.5	31.5	33.0	29.0	15.0	34.8	30.8	13.2
2.250	49.8	38.8	3.0	11	35.8	31.0	28.0	18.8	37.5	34.5	12.3
2.500	56.9	41.9	3.2	15	38.7	36.6	33.4	20.3	41.3	38.1	15.6
Average				10.8				11.6			11.0

Table E27: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0					3			4.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	11.4	8.4	13.1	6.5	3.5	18.0
1.500	38.3	25.0	3.3	13.3	21.7	31.2	27.9	7.1	28.2	24.9	10.1
2.000	48.0	35.5	4.0	12.5	31.5	29.2	25.2	18.8	37.0	33.0	11.0
2.250	49.8	38.8	3.0	11	35.8	36.0	33.0	13.8	32.0	29.0	17.8
2.500	56.9	41.9	3.2	15	38.7	30.9	27.7	26.0	33.0	29.8	23.9
Average				10.8				12.9			13.2

Table E28: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0					5			6.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.9	0.9	20.6	3.8	0.8	20.7
1.500	38.3	25.0	3.3	13.3	21.7	24.7	21.4	13.6	23.7	20.4	14.6
2.000	48.0	35.5	4.0	12.5	31.5	32.6	28.6	15.4	30.0	26.0	18.0
2.250	49.8	38.8	3.0	11	35.8	37.6	34.6	12.2	33.3	30.3	16.5
2.500	56.9	41.9	3.2	15	38.7	42.0	38.8	14.9	40.0	36.8	16.9
Average				10.8				12.6			14.0

Table E29: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8hours)

Time (hours)	0.0					7			8.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.7	0.7	20.8	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	22.3	19.0	16.0	20.9	17.6	17.4
2.000	48.0	35.5	4.0	12.5	31.5	28.0	24.0	20.0	28.5	24.5	19.5
2.250	49.8	38.8	3.0	11	35.8	30.2	27.2	19.6	29.0	26.0	20.8
2.500	56.9	41.9	3.2	15	38.7	38.0	34.8	18.9	38.0	34.8	18.9
Average				10.8				15.2			15.6

Table E30: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0					10			12.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.2	0.2	21.3
1.500	38.3	25.0	3.3	13.3	21.7	18.0	14.7	20.3	15.2	11.9	23.1
2.000	48.0	35.5	4.0	12.5	31.5	26.5	22.5	21.5	25.2	21.2	22.8
2.250	49.8	38.8	3.0	11	35.8	27.8	24.8	22.0	28.3	25.3	21.5
2.500	56.9	41.9	3.2	15	38.7	39.0	35.8	17.9	37.2	34.0	19.7
Average				10.8				16.4			17.1

Table E31: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-23hours)

Time (hours)	0.0					14			23.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	13.2	9.9	25.1	9.0	5.7	29.3
2.000	48.0	35.5	4.0	12.5	31.5	23.0	19.0	25.0	20.5	16.5	27.5
2.250	49.8	38.8	3.0	11	35.8	26.4	23.4	23.4	23.4	20.4	26.4
2.500	56.9	41.9	3.2	15	38.7	38.3	35.1	18.6	36.5	33.3	20.4
Average				10.8	17.8			19.5			

Table E32: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 23-37 hours)

Time (hours)	0.0					30			37.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	7.4	4.1	30.9	6.7	3.4	31.6
2.000	48.0	35.5	4.0	12.5	31.5	17.9	13.9	30.1	17.4	13.4	30.6
2.250	49.8	38.8	3.0	11	35.8	21.2	18.2	28.6	20.0	17.0	29.8
2.500	56.9	41.9	3.2	15	38.7	37.0	33.8	19.9	37.0	33.8	19.9
Average				10.8	20.3			20.7			

Table E33: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 37-56 hours)

Time (hours)	0.0					49			56.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	6.0	2.7	32.3	5.3	2.0	33.0
2.000	48.0	35.5	4.0	12.5	31.5	15.9	11.9	32.1	16.2	12.2	31.8
2.250	49.8	38.8	3.0	11	35.8	19.9	16.9	29.9	19.2	16.2	30.6
2.500	56.9	41.9	3.2	15	38.7	36.0	32.8	20.9	36.0	32.8	20.9
Average				10.8	21.1			21.3			

Table E34: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 56-72 hours)

Time (hours)	0.0					62			72.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	5.0	1.7	33.3	4.4	1.1	33.9
2.000	48.0	35.5	4.0	12.5	31.5	15.4	11.4	32.6	14.4	10.4	33.6
2.250	49.8	38.8	3.0	11	35.8	18.5	15.5	31.3	17.3	14.3	32.5
2.500	56.9	41.9	3.2	15	38.7	35.7	32.5	21.2	37.0	33.8	19.9
Average				10.8				21.6			21.8

Table E35: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 72-87 hours)

Time (hours)	0.0					80			87.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	3.3	0.0	35.0	3.3	0.0	35.0
2.000	48.0	35.5	4.0	12.5	31.5	14.2	10.2	33.8	14.0	10.0	34.0
2.250	49.8	38.8	3.0	11	35.8	17.0	14.0	32.8	16.9	13.9	32.9
2.500	56.9	41.9	3.2	15	38.7	36.0	32.8	20.9	37.0	33.8	19.9
Average				10.8				22.2			22.1

Table E36: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 0.775 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 87-96 hours)

Time (hours)	0.0					96		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0
0.500	14.2	2.9	2.9	11.3	0.0	2.9	0.0	11.3
1.000	24.5	12.0	3.0	12.5	9.0	3.0	0.0	21.5
1.500	38.3	25.0	3.3	13.3	21.7	3.3	0.0	35.0
2.000	48.0	35.5	4.0	12.5	31.5	13.2	9.2	34.8
2.250	49.8	38.8	3.0	11	35.8	16.4	13.4	33.4
2.500	56.9	41.9	3.2	15	38.7	37.0	33.8	19.9
Average				10.8				22.3

Table E37: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0			0.5			1.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	18.0	15.0	1.2	17.6	14.6	1.6
1.000	25.8	2.4	23.4	24.7	22.3	1.1	24.3	21.9	1.5
1.500	32.5	2.5	30.0	29.2	26.7	3.3	26.4	23.9	6.1
2.000	44.5	2.5	42.0	30.6	28.1	13.9	28.9	26.4	15.6
2.250	48.0	1.4	46.6	32.0	30.6	16.0	31.3	29.9	16.7
2.500	53.5	0.9	52.6	39.0	38.1	14.5	40.7	39.8	12.8
Average						7.1	7.8		

Table E38: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0			1.5			2.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	17.0	14.0	2.2	17.5	14.5	1.7
1.000	25.8	2.4	23.4	23.5	21.1	2.3	24.0	21.6	1.8
1.500	32.5	2.5	30.0	25.5	23.0	7.0	25.0	22.5	7.5
2.000	44.5	2.5	42.0	27.2	24.7	17.3	26.2	23.7	18.3
2.250	48.0	1.4	46.6	29.4	28.0	18.6	28.6	27.2	19.4
2.500	53.5	0.9	52.6	38.5	37.6	15.0	38.5	37.6	15.0
Average						8.9	9.1		

Table E39: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0			3			4.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	17.3	14.3	1.9	16.9	13.9	2.3
1.000	25.8	2.4	23.4	23.0	20.6	2.8	22.9	20.5	2.9
1.500	32.5	2.5	30.0	24.0	21.5	8.5	23.3	20.8	9.2
2.000	44.5	2.5	42.0	24.9	22.4	19.6	23.5	21.0	21.0
2.250	48.0	1.4	46.6	27.6	26.2	20.4	26.0	24.6	22.0
2.500	53.5	0.9	52.6	38.0	37.1	15.5	38.8	37.9	14.7
Average						9.8	10.3		

Table E40: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0			5			6.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	16.7	13.7	2.5	16.6	13.6	2.6
1.000	25.8	2.4	23.4	22.5	20.1	3.3	22.0	19.6	3.8
1.500	32.5	2.5	30.0	22.7	20.2	9.8	22.2	19.7	10.3
2.000	44.5	2.5	42.0	22.8	20.3	21.7	22.5	20.0	22.0
2.250	48.0	1.4	46.6	25.7	24.3	22.3	25.0	23.6	23.0
2.500	53.5	0.9	52.6	38.8	37.9	14.7	38.5	37.6	15.0
Average						10.6			

Table E41: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)

Time (hours)	0.0			7			8.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	16.6	13.6	2.6	17.0	14.0	2.2
1.000	25.8	2.4	23.4	21.8	19.4	4.0	21.5	19.1	4.3
1.500	32.5	2.5	30.0	21.9	19.4	10.6	21.0	18.5	11.5
2.000	44.5	2.5	42.0	22.0	19.5	22.5	21.8	19.3	22.7
2.250	48.0	1.4	46.6	24.7	23.3	23.3	24.4	23.0	23.6
2.500	53.5	0.9	52.6	38.0	37.1	15.5	37.7	36.8	15.8
Average						11.2			

Table E42: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0			10			12.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	17.0	14.0	2.2	17.0	14.0	2.2
1.000	25.8	2.4	23.4	21.0	18.6	4.8	20.0	17.6	5.8
1.500	32.5	2.5	30.0	20.2	17.7	12.3	19.8	17.3	12.7
2.000	44.5	2.5	42.0	20.9	18.4	23.6	20.9	18.4	23.6
2.250	48.0	1.4	46.6	23.7	22.3	24.3	23.0	21.6	25.0
2.500	53.5	0.9	52.6	37.3	36.4	16.2	38.4	37.5	15.1
Average						11.9			

Table E43: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-25 hours)

Time (hours)	0.0			20			25.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	16.7	13.7	2.5	16.5	13.5	2.7
1.000	25.8	2.4	23.4	17.0	14.6	8.8	16.2	13.8	9.6
1.500	32.5	2.5	30.0	17.3	14.8	15.2	16.9	14.4	15.6
2.000	44.5	2.5	42.0	19.0	16.5	25.5	18.0	15.5	26.5
2.250	48.0	1.4	46.6	20.5	19.1	27.5	21.2	19.8	26.8
2.500	53.5	0.9	52.6	36.4	35.5	17.1	34.0	33.1	19.5
Average						13.8	14.4		

Table E44: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)

Time (hours)	0.0			30			35.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	16.5	13.5	2.7	16.9	13.9	2.3
1.000	25.8	2.4	23.4	16.0	13.6	9.8	15.4	13.0	10.4
1.500	32.5	2.5	30.0	16.5	14.0	16.0	16.1	13.6	16.4
2.000	44.5	2.5	42.0	17.5	15.0	27.0	17.1	14.6	27.4
2.250	48.0	1.4	46.6	20.4	19.0	27.6	20.6	19.2	27.4
2.500	53.5	0.9	52.6	33.8	32.9	19.7	33.4	32.5	20.1
Average						14.7	14.9		

Table E45: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)

Time (hours)	0.0			45			53.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	16.4	13.4	2.8	16.0	13.0	3.2
1.000	25.8	2.4	23.4	15.0	12.6	10.8	14.5	12.1	11.3
1.500	32.5	2.5	30.0	16.0	13.5	16.5	15.7	13.2	16.8
2.000	44.5	2.5	42.0	17.2	14.7	27.3	18.0	15.5	26.5
2.250	48.0	1.4	46.6	20.5	19.1	27.5	20.4	19.0	27.6
2.500	53.5	0.9	52.6	33.5	32.6	20.0	33.3	32.4	20.2
Average						15.0	15.1		

Table E46: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 53-69 hours)

Time (hours)	0.0			59			69.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	15.7	12.7	3.5	15.5	12.5	3.7
1.000	25.8	2.4	23.4	14.0	11.6	11.8	14.6	12.2	11.2
1.500	32.5	2.5	30.0	15.5	13.0	17.0	15.3	12.8	17.2
2.000	44.5	2.5	42.0	17.6	15.1	26.9	17.7	15.2	26.8
2.250	48.0	1.4	46.6	20.2	18.8	27.8	20.0	18.6	28.0
2.500	53.5	0.9	52.6	33.1	32.2	20.4	32.2	31.3	21.3
Average						15.3	15.5		

Table E47: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)

Time (hours)	0.0			77			83.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	15.2	12.2	4.0	15.0	12.0	4.2
1.000	25.8	2.4	23.4	14.4	12.0	11.4	14.0	11.6	11.8
1.500	32.5	2.5	30.0	15.0	12.5	17.5	14.6	12.1	17.9
2.000	44.5	2.5	42.0	17.7	15.2	26.8	17.0	14.5	27.5
2.250	48.0	1.4	46.6	19.9	18.5	28.1	19.6	18.2	28.4
2.500	53.5	0.9	52.6	31.5	30.6	22.0	30.8	29.9	22.7
Average						15.7	16.1		

Table E48: Experimental data on movement of sediment in a series of pools (Pool 1; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)

Time (hours)	0.0			93			107.0		
Longitudinal distance, x (m)	Gauge height of sediment (mm)	Gauge height of flume bed (mm)	Sediment depth, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)	Gauge height of sediment (mm)	Sediment depth, (mm)	Depth of sediment removed, (mm)
0.000	6.5	6.5	0.0	6.5	0.0	0.0	6.5	0.0	0.0
0.500	19.2	3.0	16.2	15.0	12.0	4.2	14.8	11.8	4.4
1.000	25.8	2.4	23.4	14.0	11.6	11.8	13.8	11.4	12.0
1.500	32.5	2.5	30.0	14.6	12.1	17.9	14.5	12.0	18.0
2.000	44.5	2.5	42.0	17.4	14.9	27.1	17.5	15.0	27.0
2.250	48.0	1.4	46.6	19.5	18.1	28.5	19.4	18.0	28.6
2.500	53.5	0.9	52.6	30.7	29.8	22.8	30.5	29.6	23.0
Average						16.0	16.1		

Table E49: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0					0.5			1.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	17.9	15.4	5.1	6.0	3.5	17.0
1.500	28.8	25.4	1.9	3.4	23.5	39.3	37.4	-10.5	32.9	31.0	-4.1
2.000	41.1	34.9	2.0	6.2	32.9	28.7	26.7	12.4	37.9	35.9	3.2
2.250	46.2	40.7	2.5	5.5	38.2	32.5	30.0	13.7	39.7	37.2	6.5
2.500	51.0	43.1	1.3	7.9	41.8	40.0	38.7	11.0	42.4	41.1	8.6
Average				6.8				6.4			

Table E50: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0					1.5			2.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	3.5	1.0	19.5	2.4	-0.1	20.6
1.500	28.8	25.4	1.9	3.4	23.5	31.3	29.4	-2.5	29.0	27.1	-0.2
2.000	41.1	34.9	2.0	6.2	32.9	35.0	33.0	6.1	34.1	32.1	7.0
2.250	46.2	40.7	2.5	5.5	38.2	36.2	33.7	10.0	34.8	32.3	11.4
2.500	51.0	43.1	1.3	7.9	41.8	41.0	39.7	10.0	41.0	39.7	10.0
Average				6.8				8.1			

Table E51: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0					3			4.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	28.7	26.8	0.1	26.7	24.8	2.1
2.000	41.1	34.9	2.0	6.2	32.9	31.5	29.5	9.6	30.6	28.6	10.5
2.250	46.2	40.7	2.5	5.5	38.2	33.5	31.0	12.7	32.4	29.9	13.8
2.500	51.0	43.1	1.3	7.9	41.8	40.5	39.2	10.5	40.4	39.1	10.6
Average				6.8				9.5			

Table E52: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0					5			6.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	23.0	21.1	5.8	20.5	18.6	8.3
2.000	41.1	34.9	2.0	6.2	32.9	29.4	27.4	11.7	29.5	27.5	11.6
2.250	46.2	40.7	2.5	5.5	38.2	31.0	28.5	15.2	30.5	28.0	15.7
2.500	51.0	43.1	1.3	7.9	41.8	39.4	38.1	11.6	38.7	37.4	12.3
Average				6.8				11.2			11.7

Table E53: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)

Time (hours)	0.0					7			8.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	18.9	17.0	9.9	18.8	16.9	10.0
2.000	41.1	34.9	2.0	6.2	32.9	29.0	27.0	12.1	27.5	25.5	13.6
2.250	46.2	40.7	2.5	5.5	38.2	28.9	26.4	17.3	28.6	26.1	17.6
2.250	51.0	43.1	2.5	7.9	40.6	36.4	33.9	14.6	36.2	33.7	14.8
Average				6.8				12.5			12.8

Table E54: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0					10			12.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	18.2	16.3	10.6	17.9	16.0	10.9
2.000	41.1	34.9	2.0	6.2	32.9	25.5	23.5	15.6	23.7	21.7	17.4
2.250	46.2	40.7	2.5	5.5	38.2	27.0	24.5	19.2	26.4	23.9	19.8
2.500	51.0	43.1	1.3	7.9	41.8	38.8	37.5	12.2	39.2	37.9	11.8
Average				6.8				13.1			13.4

Table E55: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-25 hours)

Time (hours)	0.0					20			25.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	17.6	15.7	11.2	16.8	14.9	12.0
2.000	41.1	34.9	2.0	6.2	32.9	23.4	21.4	17.7	22.4	20.4	18.7
2.250	46.2	40.7	2.5	5.5	38.2	25.0	22.5	21.2	23.6	21.1	22.6
2.500	51.0	43.1	1.3	7.9	41.8	38.4	37.1	12.6	38.6	37.3	12.4
Average				6.8				13.8			14.2

Table E56: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)

Time (hours)	0.0					30			35.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	15.0	13.1	13.8	12.7	10.8	16.1
2.000	41.1	34.9	2.0	6.2	32.9	22.3	20.3	18.8	22.0	20.0	19.1
2.250	46.2	40.7	2.5	5.5	38.2	23.8	21.3	22.4	23.7	21.2	22.5
2.500	51.0	43.1	1.3	7.9	41.8	38.5	37.2	12.5	38.5	37.2	12.5
Average				6.8				14.5			14.9

Table E57: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)

Time (hours)	0.0					45			53.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	11.0	9.1	17.8	9.8	7.9	19.0
2.000	41.1	34.9	2.0	6.2	32.9	21.3	19.3	19.8	21.0	19.0	20.1
2.250	46.2	40.7	2.5	5.5	38.2	23.0	20.5	23.2	23.0	20.5	23.2
2.500	51.0	43.1	1.3	7.9	41.8	38.5	37.2	12.5	37.9	36.6	13.1
Average				6.8				15.3			15.6

Table E58: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 53-69 hours)

Time (hours)	0.0					59			69.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	8.8	6.9	20.0	7.7	5.8	21.1
2.000	41.1	34.9	2.0	6.2	32.9	20.8	18.8	20.3	20.6	18.6	20.5
2.250	46.2	40.7	2.5	5.5	38.2	22.8	20.3	23.4	22.5	20.0	23.7
2.500	51.0	43.1	1.3	7.9	41.8	37.9	36.6	13.1	38.6	37.3	12.4
Average				6.8				15.8			

Table E59: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)

Time (hours)	0.0					77			83.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	7.6	5.7	21.2	7.4	5.5	21.4
2.000	41.1	34.9	2.0	6.2	32.9	20.4	18.4	20.7	20.2	18.2	20.9
2.250	46.2	40.7	2.5	5.5	38.2	22.4	19.9	23.8	22.4	19.9	23.8
2.500	51.0	43.1	1.3	7.9	41.8	38.4	37.1	12.6	38.6	37.3	12.4
Average				6.8				16.0			

Table E60: Experimental data on movement of sediment in a series of pools (Pool 2; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)

Time (hours)	0.0					93			107.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.000	0.9	0.9	0.9	0	0.0	0.9	0.0	0.0	0.9	0.0	0.0
0.500	15.1	1.8	1.8	13.3	0.0	1.8	0.0	13.3	1.8	0.0	13.3
1.000	23.0	11.6	2.5	11.4	9.1	2.5	0.0	20.5	2.5	0.0	20.5
1.500	28.8	25.4	1.9	3.4	23.5	7.3	5.4	21.5	7.3	5.4	21.5
2.000	41.1	34.9	2.0	6.2	32.9	20.1	18.1	21.0	20.0	18.0	21.1
2.250	46.2	40.7	2.5	5.5	38.2	22.5	20.0	23.7	22.6	20.1	23.6
2.500	51.0	43.1	1.3	7.9	41.8	38.8	37.5	12.2	38.6	37.3	12.4
Average				6.8				16.0			

Table E61: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 0-1 hours)

Time (hours)	0.0					0.5			1.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	18.3	15.3	5.2	19.0	16.0	4.5
1.500	30.4	25.9	3.3	4.5	27.1	29.2	25.9	1.2	26.6	23.3	3.8
2.000	43.1	36.4	4.0	6.7	39.1	37.0	33.0	6.1	32.4	28.4	10.7
2.250	46.7	39.6	3.0	7.1	43.7	37.0	34.0	9.7	36.9	33.9	9.8
2.500	52.9	44.0	3.2	8.9	49.7	40.7	37.5	12.2	40.5	37.3	12.4
Average				7.0				6.8			

Table E62: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 1-2 hours)

Time (hours)	0.0					1.5			2.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	15.5	12.5	8.0	12.0	9.0	11.5
1.500	30.4	25.9	3.3	4.5	27.1	33.1	29.8	-2.7	34.7	31.4	-4.3
2.000	43.1	36.4	4.0	6.7	39.1	31.4	27.4	11.7	32.6	28.6	10.5
2.250	46.7	39.6	3.0	7.1	43.7	32.6	29.6	14.1	33.5	30.5	13.2
2.500	52.9	44.0	3.2	8.9	49.7	40.0	36.8	12.9	37.6	34.4	15.3
Average				7.0				8.2			

Table E63: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 2-4 hours)

Time (hours)	0.0					3			4.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	5.3	2.3	18.2	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	31.0	27.7	-0.6	29.0	25.7	1.4
2.000	43.1	36.4	4.0	6.7	39.1	34.5	30.5	8.6	33.5	29.5	9.6
2.250	46.7	39.6	3.0	7.1	43.7	35.9	32.9	10.8	35.3	32.3	11.4
2.500	52.9	44.0	3.2	8.9	49.7	41.5	38.3	11.4	41.0	37.8	11.9
Average				7.0				8.8			

Table E64: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 4-6 hours)

Time (hours)	0.0					5			6.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	28.1	24.8	2.3	26.0	22.7	4.4
2.000	43.1	36.4	4.0	6.7	39.1	32.9	28.9	10.2	32.7	28.7	10.4
2.250	46.7	39.6	3.0	7.1	43.7	33.8	30.8	12.9	33.0	30.0	13.7
2.500	52.9	44.0	3.2	8.9	49.7	40.9	37.7	12.0	39.3	36.1	13.6
Average				7.0				10.2			10.8

Table E65: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 6-8 hours)

Time (hours)	0.0					7			8.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	23.0	19.7	7.4	22.3	19.0	8.1
2.000	43.1	36.4	4.0	6.7	39.1	31.3	27.3	11.8	30.7	26.7	12.4
2.250	46.7	39.6	3.0	7.1	43.7	32.7	29.7	14.0	30.7	27.7	16.0
2.500	52.9	44.0	3.2	8.9	49.7	40.0	36.8	12.9	38.8	35.6	14.1
Average				7.0				11.4			12.1

Table E66: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 8-12 hours)

Time (hours)	0.0					10			12.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	20.0	16.7	10.4	18.5	15.2	11.9
2.000	43.1	36.4	4.0	6.7	39.1	29.0	25.0	14.1	28.4	24.4	14.7
2.250	46.7	39.6	3.0	7.1	43.7	31.4	28.4	15.3	30.0	27.0	16.7
2.500	52.9	44.0	3.2	8.9	49.7	39.5	36.3	13.4	40.0	36.8	12.9
Average				7.0				12.4			12.9

Table E67: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 12-25 hours)

Time (hours)	0.0					20			25.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	17.4	14.1	13.0	17.2	13.9	13.2
2.000	43.1	36.4	4.0	6.7	39.1	25.2	21.2	17.9	25.0	21.0	18.1
2.250	46.7	39.6	3.0	7.1	43.7	28.3	25.3	18.4	27.6	24.6	19.1
2.500	52.9	44.0	3.2	8.9	49.7	38.8	35.6	14.1	37.9	34.7	15.0
Average				7.0				13.9			14.2

Table E68: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 25-35 hours)

Time (hours)	0.0					30			35.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	17.0	13.7	13.4	16.4	13.1	14.0
2.000	43.1	36.4	4.0	6.7	39.1	24.2	20.2	18.9	24.0	20.0	19.1
2.250	46.7	39.6	3.0	7.1	43.7	27.6	24.6	19.1	27.3	24.3	19.4
2.500	52.9	44.0	3.2	8.9	49.7	36.9	33.7	16.0	36.6	33.4	16.3
Average				7.0				14.5			14.7

Table E69: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 35-53 hours)

Time (hours)	0.0					45			53.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	14.0	10.7	16.4	12.0	8.7	18.4
2.000	43.1	36.4	4.0	6.7	39.1	24.5	20.5	18.6	23.9	19.9	19.2
2.250	46.7	39.6	3.0	7.1	43.7	27.0	24.0	19.7	26.9	23.9	19.8
2.500	52.9	44.0	3.2	8.9	49.7	36.4	33.2	16.5	36.4	33.2	16.5
Average				7.0				15.0			15.4

Table E70: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 53-69 hours)

Time (hours)	0.0					59			69.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	7.4	4.1	23.0	7.2	3.9	23.2
2.000	43.1	36.4	4.0	6.7	39.1	23.9	19.9	19.2	23.5	19.5	19.6
2.250	46.7	39.6	3.0	7.1	43.7	26.3	23.3	20.4	25.9	22.9	20.8
2.500	52.9	44.0	3.2	8.9	49.7	38.9	35.7	14.0	38.9	35.7	14.0
Average				7.0				15.8			

Table E71: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 69-83 hours)

Time (hours)	0.0					77			83.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	7.1	3.8	23.3	7.0	3.7	23.4
2.000	43.1	36.4	4.0	6.7	39.1	22.8	18.8	20.3	22.5	18.5	20.6
2.250	46.7	39.6	3.0	7.1	43.7	25.8	22.8	20.9	25.8	22.8	20.9
2.500	52.9	44.0	3.2	8.9	49.7	38.9	35.7	14.0	38.7	35.5	14.2
Average				7.0				16.0			

Table E72: Experimental data on movement of sediment in a series of pools (Pool 3; Q_w : 11.1 litres/sec; D_{50} : 1.15 mm; b: 380 mm; Pool length, L: 2.5 m; Measuring times range: 83-107 hours)

Time (hours)	0.0					93			107.0		
Longitudinal distance, x (m)	Gauge height of fully filled pool (mm)	Gauge height of sediment filled pool (mm)	Gauge height of flume bed (mm)	Scour depth (mm)	Sediment depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)	Gauge height of sediment (mm)	Sediment depth (mm)	Scour depth (mm)
0.00	1.3	1.3	1.3	0	0.0	1.3	0.0	0.0	1.3	0.0	0.0
0.500	16.2	2.9	2.9	13.3	13.3	2.9	0.0	13.3	2.9	0.0	13.3
1.000	23.5	15.0	3.0	8.5	20.5	3.0	0.0	20.5	3.0	0.0	20.5
1.500	30.4	25.9	3.3	4.5	27.1	6.9	3.6	23.5	7.0	3.7	23.4
2.000	43.1	36.4	4.0	6.7	39.1	22.5	18.5	20.6	22.5	18.5	20.6
2.250	46.7	39.6	3.0	7.1	43.7	25.7	22.7	21.0	25.6	22.6	21.1
2.500	52.9	44.0	3.2	8.9	49.7	38.8	35.6	14.1	39.0	35.8	13.9
Average				7.0				16.1			

APPENDIX F: Flow charts

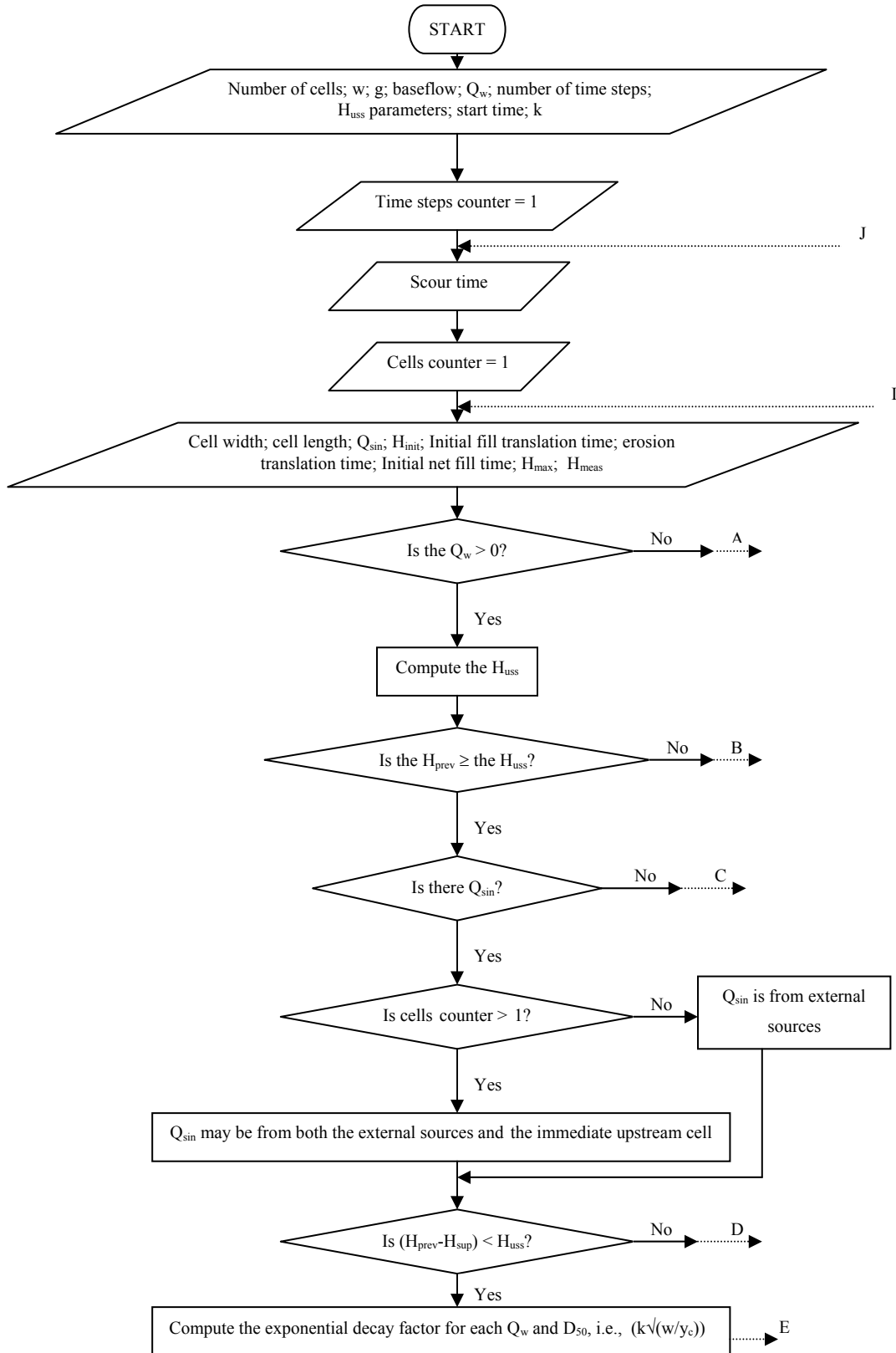


Figure F1: Flowchart of an inverted sediment budget model for a single steady discharge episode

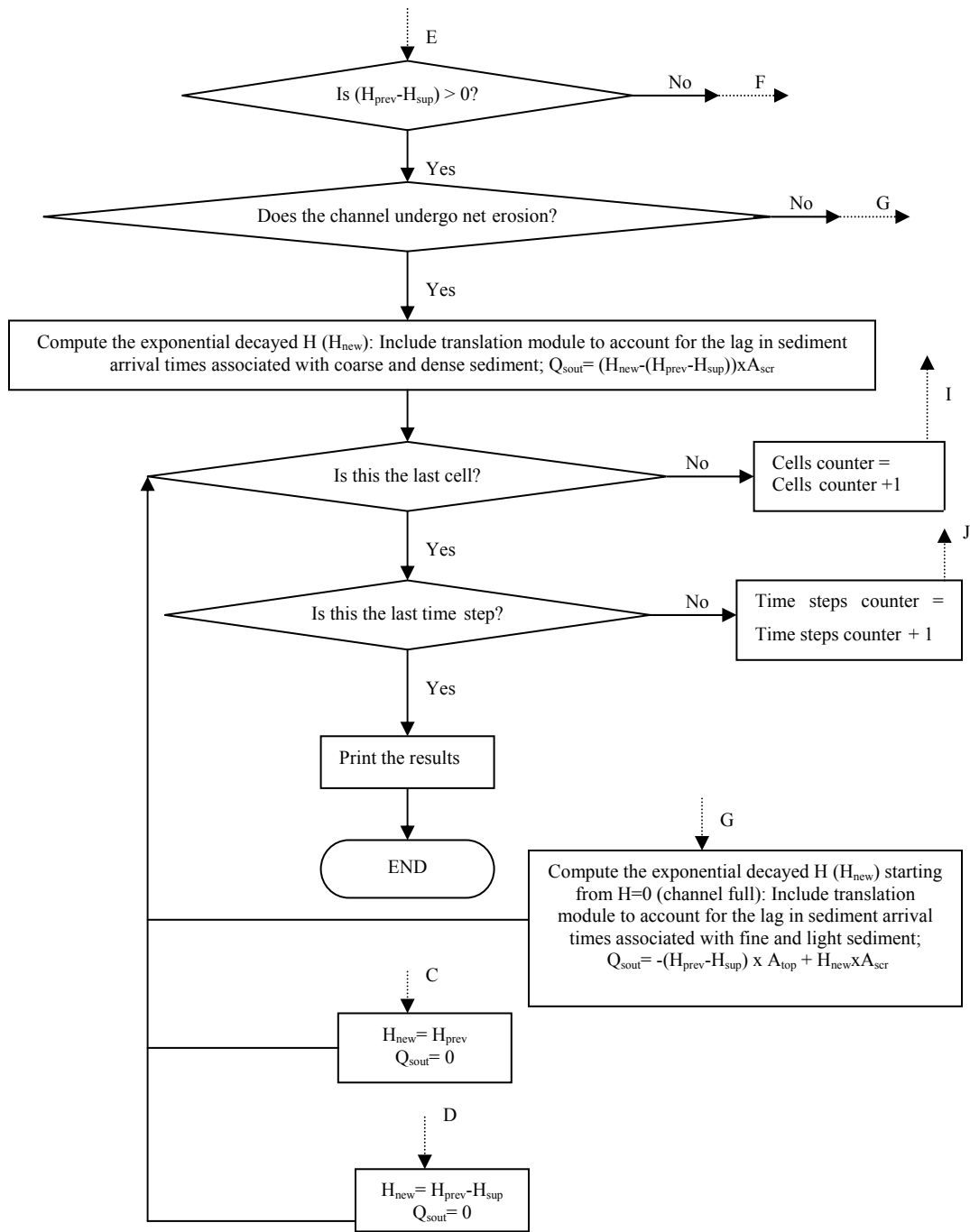


Figure F1 Continued: Flowchart of an inverted sediment budget model for a single steady discharge episode

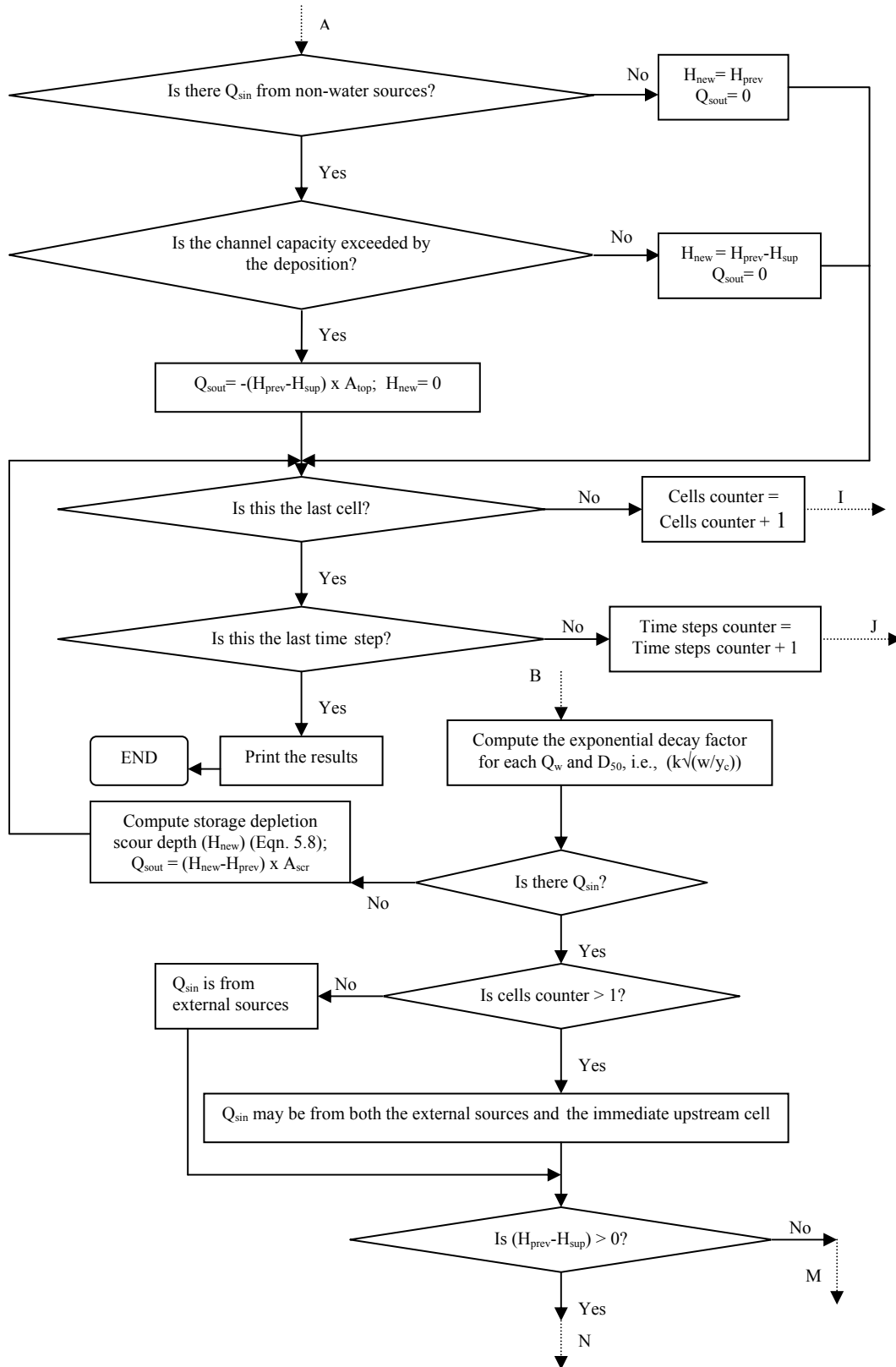


Figure F1 Continued: Flowchart of an inverted sediment budget model for a single steady discharge episode

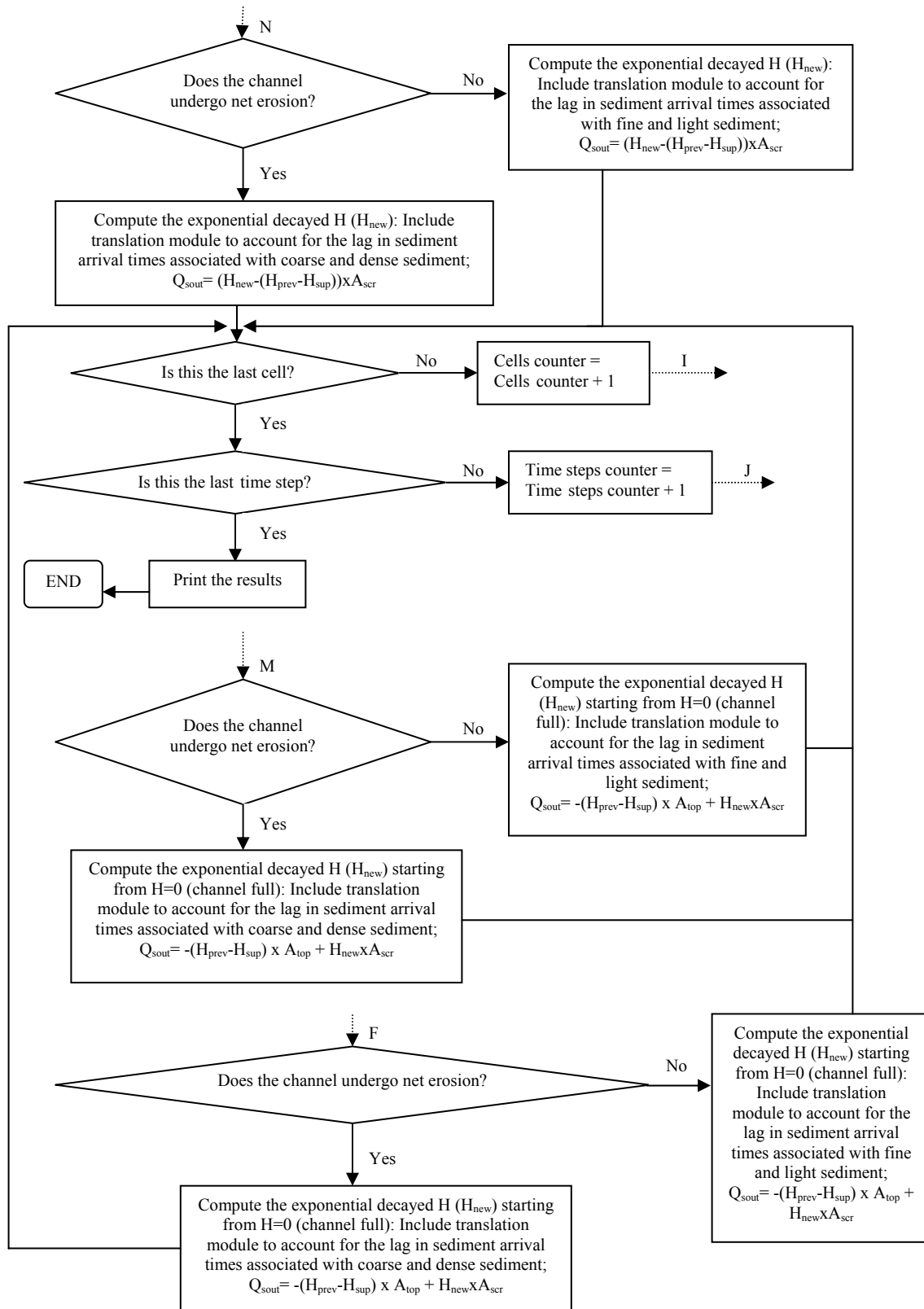


Figure F1 Continued: Flowchart of an inverted sediment budget model for a single steady discharge episode

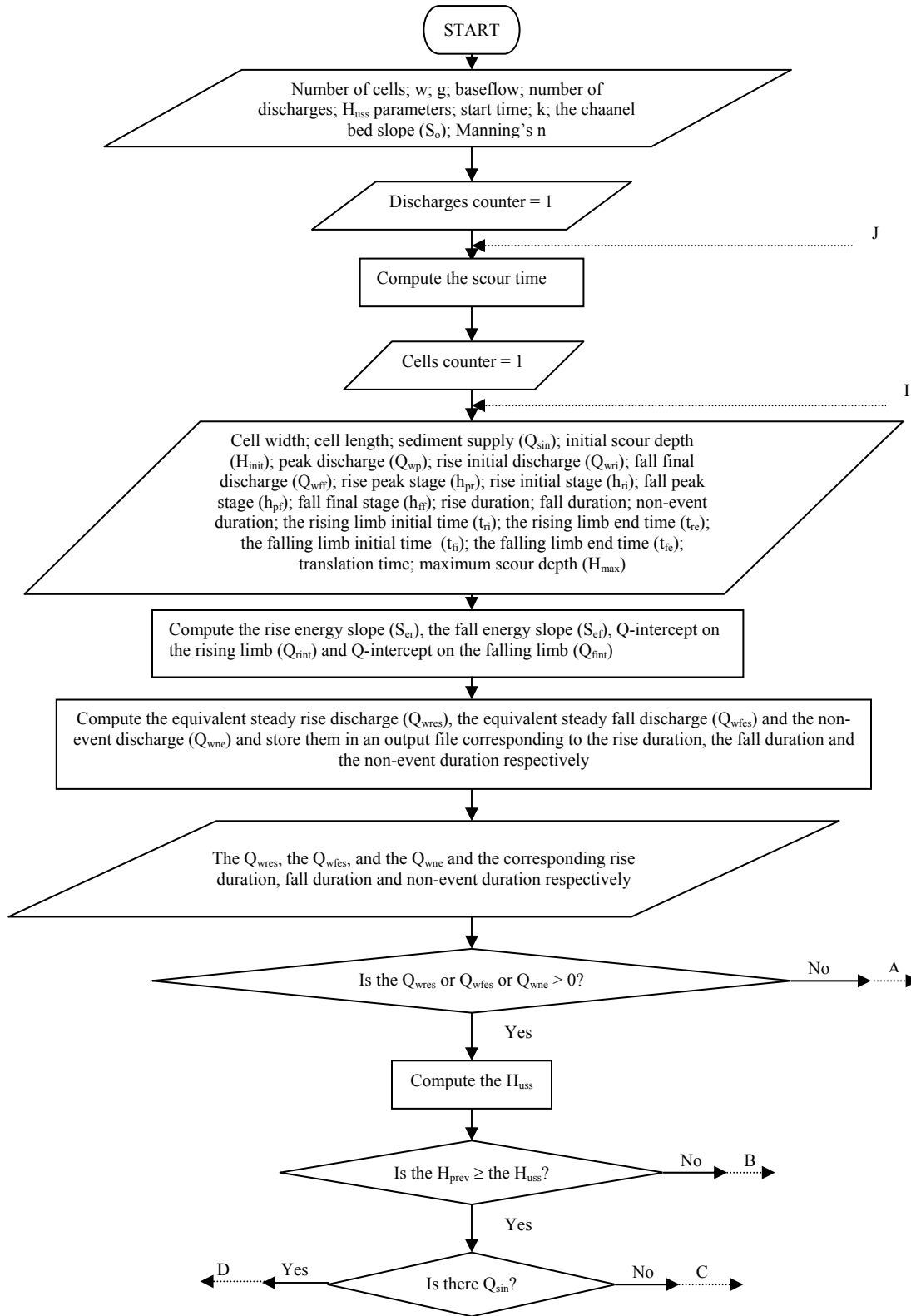


Figure F2: Flowchart of unsteady flow inverted episodic sediment budget model of rise-peak-fall discharge hydrographs

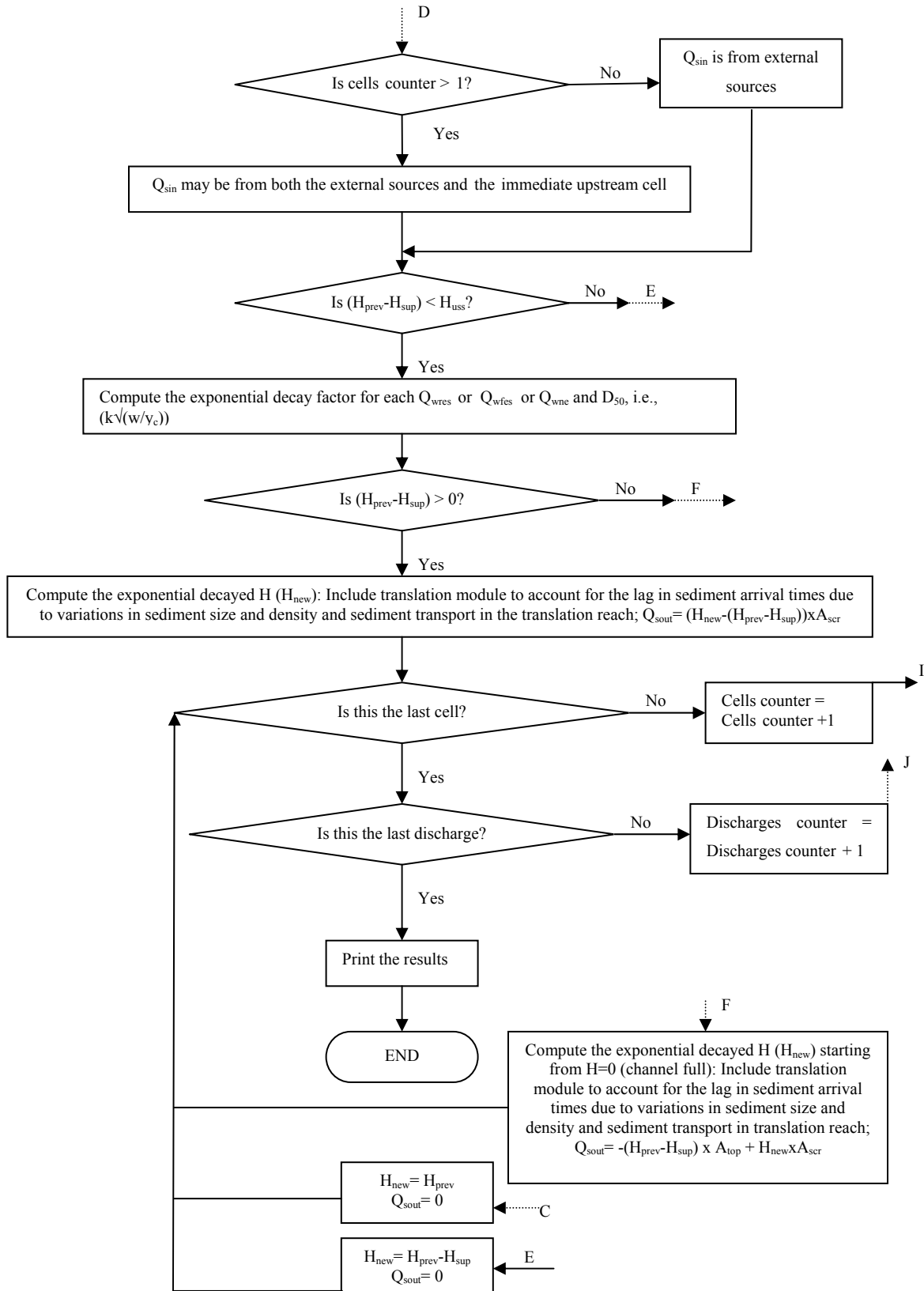


Figure F2 Continued: Flowchart of unsteady flow inverted episodic sediment budget model of rise-peak-fall discharge hydrographs

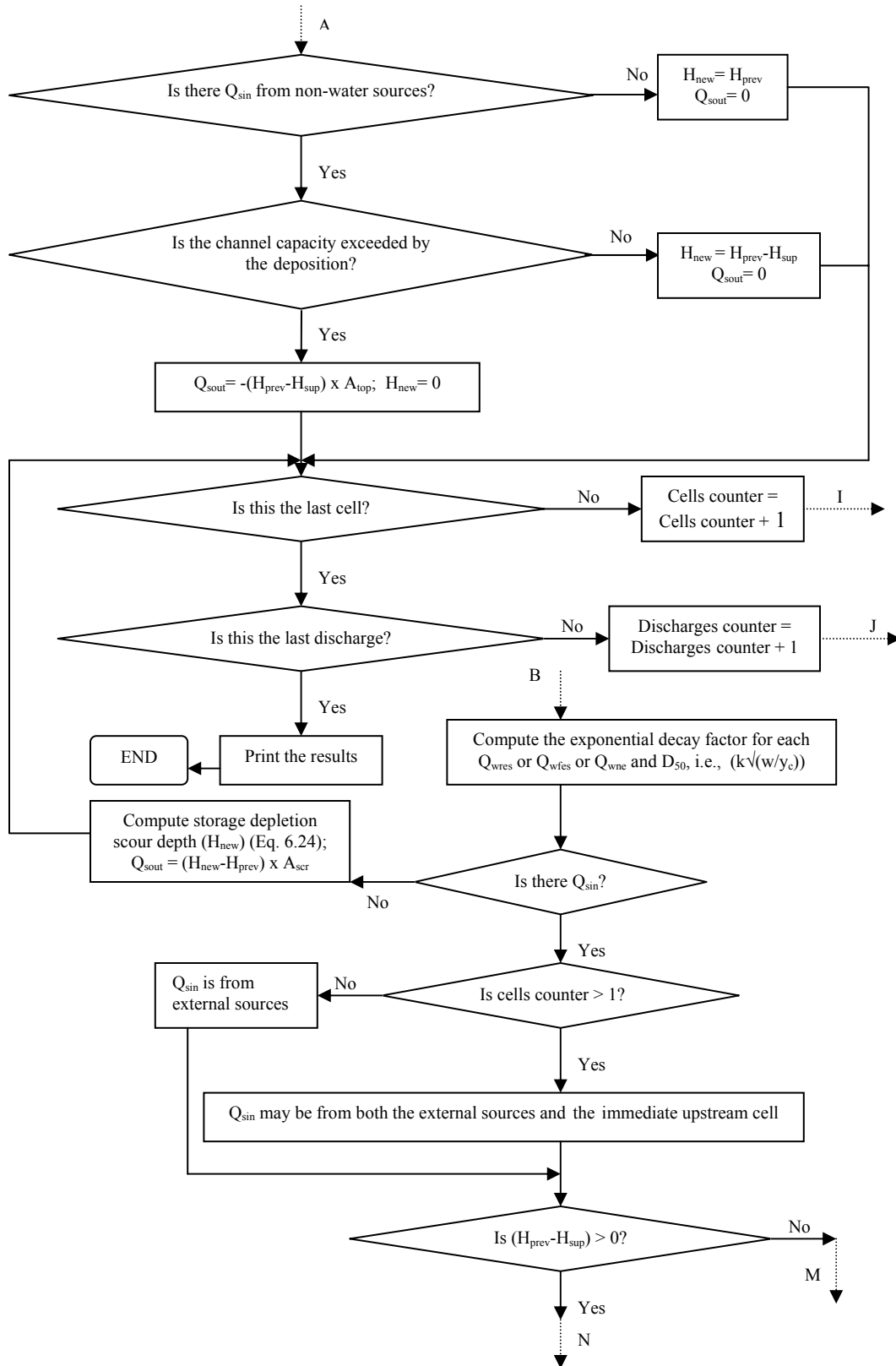


Figure F2 Continued: Flowchart of unsteady flow inverted episodic sediment budget model of rise-peak-fall discharge hydrographs

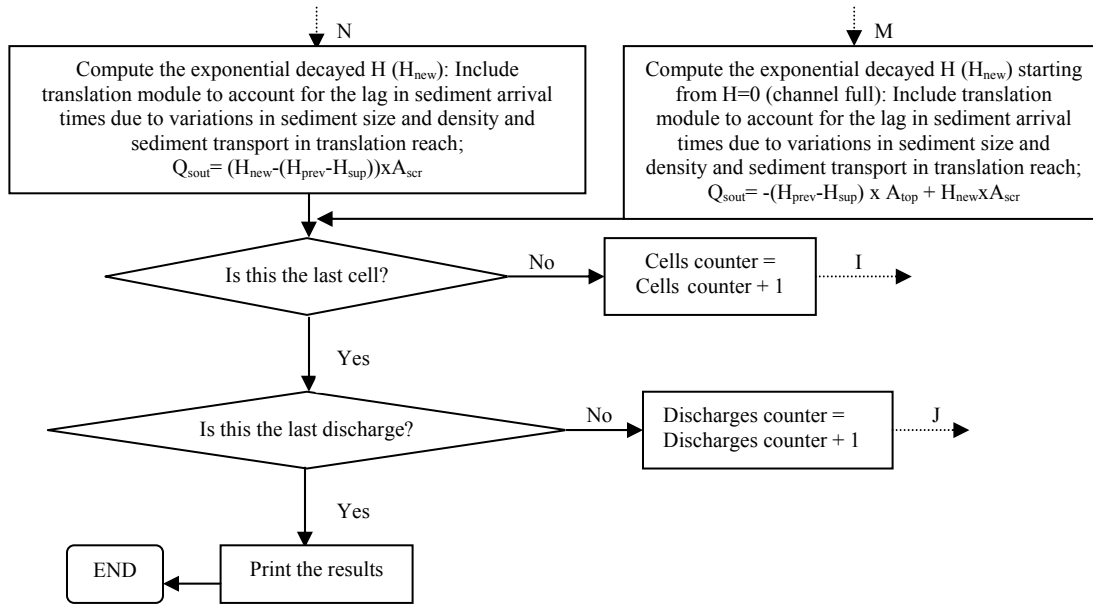


Figure F2 Continued: Flowchart of unsteady flow inverted episodic sediment budget model of rise-peak-fall discharge hydrographs

APPENDIX G: Codes for Inverted Episodic Sediment Budget Model (G1 and G2-provided in CD)

APPENDIX H: Chapter 6 appendix**6.1H Dimensional Analysis**

Dimensional analysis is a method for reducing the number of variables in an experiment in order to simplify the process for describing the relationship among those variables (Chandler, 1998). If it is possible to identify the factors involved in a physical situation, dimensional analysis can provide a relationship between them. Dimensional analysis has been widely applied in the field of sediment transport to reduce the large number of physical parameters to a few dimensionless groups. The dimensionless groups describe the relationship between the variables.

Though dimensionless parameters are qualitative expressions, when converted to quantitative forms they can be used to obtain any unknown factors from experimental analysis. Sediment transport expressions must necessarily be based on dimensional analysis, since the details of the physical processes and their interactions are not well known (Kamphuis, 2002).

The Buckingham π theorem is the dimensional analysis method most frequently used in the generation of the dimensionless groups from the physical variables affecting the phenomenon of interest. This is because the Buckingham π theorem gives a good generalized strategy for obtaining dimensionless groups. However, other methods such as the method of indices are also occasionally used.

Buckingham π theorem is a key theorem in dimensional analysis. Buckingham π theorem states that if there is a functional relationship between n^* physical variables, all of which can be expressed in terms of m fundamental dimensions (e.g., Mass (M), Length (L) and Time (T)), then n^*-m dimensionless groups (π groups) can be formed from the original n^* variables (Henderson, 1966).

Buckingham π theorem describes how every physically meaningful (dimensionally homogeneous) equation involving n^* variables can be equivalently rewritten as an

equation of n^*-m dimensionless parameters. Furthermore, and most importantly, it provides a method for computing sets of dimensionless parameters from the given variables, even if the form of the equation is still unknown.

The total number of fundamental dimensions in all the physical variables is used as criterion for determining the number of repeating variables in the Buckingham π theorem. A repeating variable is a variable that occurs in all or most of the dimensionless groups. The number of repeating variables is equal to the total number of fundamental dimensions (m) in all the variables. The total number of fundamental dimensions is determined from the fundamental dimensions of all the variables but with each fundamental dimension counted only once. In other words, a specific fundamental dimension such as L for any physical quantity with length as a fundamental dimension may appear in more than one variable but is only counted once. It is important to note that a dependent variable cannot be chosen as a repeating variable. Further, the repeating variables must collectively have all the fundamental dimensions contained in all the physical variables. However, a combination of the repeating variables must not form a dimensionless group.

Each Buckingham π equation (constituting each dimensionless group) is set up in terms of the product of all the repeating variables and a non-repeating variable. Each repeating variable is raised to a different exponent in each π equation. The dimensional homogeneity of the fundamental dimensions of the physical variables in each side of the π equation is then used to determine the exponents of the physical variables for each dimensionless group.

The Buckingham's π theorem only provides away of generating sets of dimensionless parameters and does not choose the most physically meaningful. This is the work of the expert dealing with the problem being expressed in terms of the dimensionless groups. He/she must have good understanding of the physical variables affecting the phenomenon of interest to ensure correct choice of the relevant physical variables. The dimensionless

groups allow collapsing of disorganized data into a few relations between the dimensionless parameters.

The Buckingham π theorem has therefore been used to derive the dimensionless groups for determining the relationship between H_{uss} and y_c and between H and t on the basis of the experimental results of the H_{uss} and the storage depletion curve (see sections 6.2 and 6.3) respectively.

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