Supplement of

Coarse bedload routing and dispersion through tributary confluences

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Supplementary Material

A: Study site topography and hydrology data

We measured cross sections at each seed reach corresponding to the placement of pressure transducers in the active channel. Cross sections were measured perpendicular to the flow direction from bankfull to bankfull at a point spacing of ~0.5-1 m. We placed our cross sections as to capture the channel characteristics of the seed reaches where particle tracers were initially located. These cross sections were the basis of our calculations of I^* and critical Shields number.

Figure S1: Moose Creek seed reach in the upper confluence.

14 Figure S2: Martin Creek seed reach in the upper confluence.

15
16 Figure S3: The control reach.

17
18 Figure S4: Martin Creek seed reach in the lower confluence.

Figure S5: East Fork Bitterroot seed reach in the lower confluence.

We used transducer data at each study reach to produce flood hydrographs for each seed reach at the study site. Mueller et al. (2005) and Recking (2013) thresholds for incipient motion are indicated on each figure, as is the bankfull level.

Figure S6: 2014 stage hydrograph at the Moose Creek (upper confluence) transducer.

Figure S7: 2014 stage hydrograph at the Martin Creek (upper confluence) transducer.

Figure S8: 2014 stage hydrograph at the control reach.

Figure S9: 2014 stage hydrograph at the Martin Creek (lower confluence) transducer.

B: Tracer data

To transform total station-measured data of tracer displacement to streamwise transport distances, we employed open-source MATLAB code called “xy2sn.” This code transforms spatial data from Cartesian coordinates to streamwise coordinates, with a downstream (s) and lateral (cross-channel, n) component. To determine the lateral component, we input a digitized stream centerline for each study reach, comprised of 15-20 points corroborated by field notes. This digitized centerline spanned the distance of tracer displacement in each study reach by ~10 m on both ends. We input the Cartesian coordinate data, entered in points of the centerline, and received transformed coordinate data for both pre and post-flood tracer locations at each reach. We then subtracted the streamwise distance of pre-flood tracers from their post-flood locations to compute transport distance downstream. In the rare cases that pre-flood streamwise distance exceeded post-flood distance (always occurring within the antenna measurement error), we considered the tracer stationary. Tables S1 and S2 show travel distances of recovered tracers for each study reach, with tag ID and b-axis included.

Moose				
Tag ID	Npos	Spos	Dist (m)	B (mm)
91806	0.347871	0.142189	2.85	86
91821	2.613436	0.175178	3.55	80
91823	-2.74345	0.152109	18.28	100
91827	-1.10628	0.253458	3.41	101
91828	-1.75281	0.11617	19.98	102
91834	2.029138	0.328281	1.76	85
91835	0.87074	0.182494	3.15	79
91836	0.485809	0.312603	5.7	64
91841	-0.50899	0.144468	23.7	92
91843	-2.54474	0.35372	12.31	85
91849	-0.70138	0.369063	0	100
91859	0.63181	0.206109	9.8	98
91865	1.685904	0.097638	0.2	79
91868	1.115882	0.144123	3.74	56
91873	0.925781	0.377128	0.69	90
91874	2.579787	0.387635	0	86
91895	-0.20559	0.070381	12.95	96
91903	0.043055	0.249637	2.74	104
91907	-0.66348	0.284096	2.79	67
91908	1.259715	0.281014	0.71	108
91912	-2.64999	0.217697	11.15	81
91914	-1.25508	0.307678	6.67	127
91922	-0.18497	0.175549	17.06	61
91928	-2.36181	0.333267	11.46	83
91931	1.577886	0.202198	0	116
91932	-1.08573	0.183216	24.5	72

91933	-1.0116	0.073397	0	126
91945	0.191063	0.280473	16.86	114
91947	2.225698	0.29073	4.01	63
91949	-2.05637	0.187514	12.6	84
91950	-2.15992	0.307369	17.01	92
91956	-0.24266	0.310036	3.62	62
91965	-0.34251	0.203649	7.83	119
91970	-1.79743	0.154154	12.97	76
91972	2.848032	0.247538	0.44	96
91995	-2.06504	0.279536	14.53	106
92007	2.038426	0.357057	9.95	92
92020	2.629909	0.205983	0	106
92023	1.998442	0.25204	6.21	69
92052	-1.28277	0.334488	7.41	67
92053	0.07675	0.105907	7.38	67
92055	-1.38497	0.145761	14.39	85
92063	3.712752	0.204877	0	87
92066	0.81126	0.064915	0.41	84
92092	1.240442	0.320425	3.53	88
92093	0.407138	0.340504	5.35	108
92095	-0.46274	0.339865	12.77	70
92102	-2.30538	0.256231	13.2	98
505514	1.119101	0.345753	5.78	76
505528	2.88587	0.29758	1.36	73
505539	-1.58891	0.21266	3	73
505587	-1.642	0.356303	11.96	94
505596	3.677135	0.175887	0	61

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Mart_Up				
Tag ID	Npos	Spos	Dist (m)	B (mm)

91805	-1.18719	0.366912	6.23	109
91807	-0.2186	0.15831	3.42	73
91824	-0.10247	0.244096	0	86
91825	-2.29226	0.240954	3.87	97
91837	0.384815	0.26385	1.49	82
91844	0.118965	0.222598	2.3	85
91846	1.817712	0.168724	2.82	80
91853	-1.21065	0.22081	0.84	83
91864	1.534454	0.36401	0	94
91879	1.48499	0.223299	0	104
91891	-0.99591	0.158764	0.62	96
91897	1.292956	0.075429	11	69
91900	1.620956	0.287724	3.83	100
91901	-0.42546	0.227927	8.38	93
91906	0.502415	0.320518	1.18	112
91911	1.988038	0.249434	1.91	91
91915	-0.24941	0.097927	4.52	80
91934	-1.55962	0.295468	0.46	77
91943	-1.01983	0.118911	6.83	63
91953	-0.44861	0.192508	1.54	99
91957	-1.98316	0.163515	0.38	85
91978	1.315128	0.153137	6.08	65
91999	-1.41616	0.099571	2.13	96
92008	0.44748	0.157352	1.69	72
92010	0.45916	0.184033	5.44	72
92027	-0.8391	0.066071	20.67	83
92043	-1.89738	0.262797	5.48	71
92054	0.88396	0.263813	0	75
92078	1.905724	0.263589	5.83	83
92082	0.210165	0.392073	4.98	73
92096	-1.18581	0.32383	0.26	70

505500	1.858562	0.150735	6.39	51
505504	0.942786	0.393802	4.38	74
505508	-1.14672	0.259422	0.62	48
505512	1.353207	0.314726	7.7	89
505513	-0.47801	0.280437	0.55	83
505550	-1.6467	0.200699	0	61
505553	0.648034	0.06137	3.92	84
505568	-1.80318	0.117501	11.17	94
505573	-2.10789	0.22256	10.01	69
505586	-0.66964	0.395081	0	66
505598	-2.24663	0.203937	0.79	75

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Control				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91812	6.242331	0.172297	0.74	112
91822	2.288752	0.175454	13.29	73
91838	-5.21323	0.199262	0	73
91842	0.351121	0.043198	1.64	106
91845	6.056943	0.095899	0.7	77
91847	-4.20195	0.129688	0.66	87
91848	-1.15284	0.111054	8.48	90
91854	7.25586	0.113613	2.19	65
91862	-0.89323	0.069074	4.71	63
91870	-3.33846	0.143647	2.03	113
91878	5.428543	0.008826	0.28	104
91881	5.332243	0.157948	2.9	99
91885	-1.6546	0.072082	8.19	80
91887	1.56427	0.170958	14.28	61
91888	-2.17945	0.075708	16.69	84
91893	3.655599	0.117982	9.08	80

91898	4.006979	0.095106	4.94	70
91904	-4.49714	0.088934	0.37	84
91913	4.195602	0.019427	0.56	72
91916	-5.082	0.179459	1.34	63
91921	1.082968	0.188328	0.68	86
91924	-4.2694	0.112633	1.1	83
91926	3.494922	0.157823	5.75	76
91930	-2.59657	0.143647	2.53	74
91946	-2.77146	0.172007	0	75
91959	-3.74222	0.085332	0.85	85
91960	0.257218	0.192349	0.58	125
91964	-0.9496	0.088858	4.56	108
91977	5.746844	0.035957	9.41	90
91979	1.293594	0.034377	11.04	95
91980	3.057424	0.20039	7.22	88
91991	7.018058	0.083119	0.64	93
91993	0.005751	0.081093	22.39	101
92003	2.468248	0.037926	3.8	112
92004	3.011124	0.014172	2.71	88
92009	-0.31305	0.187927	18.51	62
92011	2.425993	0.213048	3.02	93
92012	2.541386	0.099443	2.9	90
92014	-0.83511	0.131634	0	83
92026	5.339401	0	0	106
92030	1.162246	0.206704	1.02	90
92032	-1.90012	0.097388	4.17	110
92036	5.05439	0.205028	0.44	80
92042	-0.03752	0.20693	8.3	78
92046	-4.29668	0.14639	0	96
92048	4.461366	0.156192	9.78	80
92050	-1.73908	0.169109	2.95	84

92051	2.089909	0.187298	0.27	108
92057	-4.32479	0.189194	0.71	97
92076	3.18917	0.095734	11.17	79
92086	4.001639	0.203783	1.03	82
505403	1.753948	0.101087	1.14	119
505415	0.701398	0.049349	0.41	118
505426	2.274472	0.026101	0.68	116
505430	-1.76789	0.122863	4.72	111
505432	0.534506	0.172163	6.5	107
505444	-0.20259	0.110436	0.85	110
505450	-4.65177	0.069074	0	136
505453	3.668802	0.071886	2.99	106
505462	-1.1411	0.183668	7.65	116
505464	-3.23588	0.126553	0.64	114
505476	-3.05394	0.202321	0.78	109
505477	-0.74928	0.208205	0	122
505480	1.688456	0.049156	8.22	105
505486	-2.31134	0.0554	3.08	127
505487	4.270355	0.228424	1.09	112
505501	-3.18945	0.184213	3.93	53
505507	4.109607	0.003644	0	83
505530	-2.06484	0.207409	10.43	80
505535	1.520339	0.119924	13.68	71
505536	3.315041	0.030921	1.17	87
505546	-2.04358	0.181668	0.38	86
505554	2.530991	0.11633	13.86	55
505555	-1.76694	0.141589	5.15	96
505562	4.726006	0.114483	0	90
505564	-4.68609	0.169067	0	63
505575	4.59321	0.055968	0	90
505577	-1.41627	0.050951	1.4	101

505578	1.472548	0.078042	2.7	88
505579	-3.66187	0.172695	0	95
505582	0.731063	0.105147	22.71	76
505592	5.024893	0.081746	3.09	71
505599	7.11762	0.170051	0.69	75

Mart_Lo				
Tag ID	Npos	Spos	Dist	B (mm)
			(m)	
91975	-0.87994	0.090752	0.91	118
91976	0.21253	0.103514	0	92
91981	-0.38033	0.110382	0	118
91994	0.283111	0.128573	1.89	87
91997	1.264003	0.092874	4.74	91
92000	2.635628	0.091249	0.34	90
92001	0.121602	0.124659	10.79	98
92017	0.501803	0.096951	0.53	73
92031	0.896232	0.113737	14.52	70
92037	-1.23992	0.050148	0	85
92058	-1.02252	0.076035	10.13	75
92059	-1.73387	0.088785	13.99	110
92060	1.334197	0.054954	0	134
92077	-1.38088	0.118536	1.14	77
92081	-0.17425	0.039033	10.02	80
92084	2.636988	0.042531	7.67	101
92100	-0.81014	0.08144	1.04	110
92104	2.357163	0.081854	29.42	106
505400	0.513401	0.116196	1.27	93
505401	0.060495	0.109875	1.7	88
505402	0.171348	0.081243	62.06	96
505404	-0.0373	0.049765	54.58	76

505405	2.646222	0.095809	0.88	116
505410	-2.13631	0.055247	0.38	91
505411	-0.59393	0.097357	11.27	78
505412	1.304788	0.104573	37.73	80
505413	0.917549	0.113944	21.2	106
505414	0.147906	0.044099	4.03	75
505416	1.673985	0.115217	1.52	72
505417	-2.44185	0.067381	0	106
505419	1.252622	0.111352	0.43	113
505422	0.091691	0.122246	39.52	96
505423	-0.99302	0.117713	1.87	95
505424	1.2683	0.038744	5.98	100
505425	0.229578	0.0909	0	69
505427	1.001765	0.124321	30.24	81
505433	1.222487	0.126757	1.6	71
505435	-1.47017	0.043198	26.08	89
505436	1.327014	0.086078	44.39	74
505439	-0.8813	0.0241	132.93	80
505446	-1.21765	0.073083	38.46	97
505447	-2.30864	0.110101	0.59	89
505448	1.835198	0.124727	0	128
505449	2.599856	0.112762	1.67	76
505451	1.393119	0.120818	0.36	87
505454	-1.75918	0.077262	1.05	95
505455	-0.66184	0.028199	3.16	131
505457	1.556394	0.016958	1.7	89
505458	-0.62793	0.123016	0.33	90
505459	0.264943	0.0547	59.75	99
505460	0.434964	0.113737	50.68	88
505461	-0.18191	0.113503	36.94	102
505463	-2.0408	0.112889	0.3	88

505465	-0.83736	0.114945	38.12	80
505468	2.69943	0.017658	1.18	66
505471	-0.28525	0.12453	0.89	123
505472	1.017805	0.049709	0	83
505473	2.912792	0.055989	2.9	89
505474	-1.2313	0.122447	4.68	84
505475	2.503539	0.085633	25.51	63
505478	-0.05648	0.072525	1.92	97
505479	-0.67547	0.126423	11.93	92
505483	-1.67541	0.021492	1.83	125
505485	-1.23299	0.128342	0.58	87
505491	-2.22115	0.074029	1.13	120
505493	0.643943	0.01531	70.05	80
505495	-1.84103	0.101191	0.25	117
505496	-1.17711	0.098487	20.67	87
505497	-0.54518	0.01607	33.15	77
505499	1.937815	0.11377	2.7	94
505543	0.843408	0.121555	34.14	58

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EFB				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91810	-5.37404	0.125135	80.88	96
91819	-2.41495	0.020828	203.19	83
91830	-2.57535	0.082293	27.43	75
91832	-5.45584	0.010076	43.7	83
91851	-5.72994	0.025039	29.27	64
91855	-5.71705	0.013163	35.58	108
91856	-7.4354	0.125855	0.33	59
91860	-4.86109	0.129452	0.51	64
91867	-5.79578	0.028458	1.95	59

91875	-3.26957	0.015949	103.33	79
91876	-4.07995	0.017883	149.42	79
91884	-2.79892	0.048128	64.59	112
91899	-4.57462	0.013471	26.46	70
91902	-6.97099	0.127865	0.21	112
91917	-3.18908	0.044871	42.13	100
91920	-3.72522	0.012115	25.39	63
91925	-2.23893	0.080617	9.87	93
91938	-3.80956	0.057261	0.76	83
91940	0.205836	0.065327	68.33	125
91942	-2.09064	0.062175	5.79	99
91952	-1.79769	0.080974	4.96	123
91955	-5.10694	0.023277	28.96	103
91961	-4.16952	0.021717	62.1	79
91963	-1.54119	0.056915	3.45	87
91973	-1.55581	0.062036	49.86	108
91985	-2.30219	0.079488	19.16	113
91986	-2.56758	0.04362	35.27	90
91987	-3.92773	0.034078	44.33	98
91988	-3.52269	0.123892	0.3	108
91990	-0.98828	0.07359	159.55	73
91992	-4.62649	0.050233	1.98	115
91998	-5.14162	0.122912	0.51	136
92002	-2.63338	0.027324	89.39	76
92015	-3.97261	0.041192	6.05	83
92018	-6.11673	0.03256	24.67	77
92019	-2.62124	0.014367	98.72	99
92021	-2.79728	0.08551	11.9	76
92033	-5.44875	0.036166	30.53	89
92038	-6.60564	0.124733	0	82
92040	-3.47967	0.026907	211.59	77

92041	-4.08833	0.050426	11.02	87
92061	-6.34401	0.130096	0.91	74
92065	-3.24281	0.032976	193.53	86
92071	-2.93431	0.024066	40.72	102
92072	-2.25946	0.065895	39.52	77
92074	-1.5197	0.066037	83.07	124
92075	-4.06068	0.028849	52.05	84
92088	-2.42627	0.051637	82.09	84
92094	-1.04078	0.07908	46.07	81
92097	-2.55963	0.039482	51.22	86
505420	-2.99527	0.082181	18.32	89
505428	-7.63753	0.127793	0	116
505442	-6.16648	0.127283	0.5	134
505466	-4.31428	0.128329	0.32	129
505467	-0.59862	0.067226	52.3	112
505482	-4.16201	0.046772	27.24	108
505484	-5.99752	0.123009	0.38	137
505489	-3.38073	0.078725	11.76	144
505498	-2.19238	0.08551	6.69	100
505506	-2.02049	0.024707	25.81	77
505517	-2.97914	0.065642	0.97	90
505520	-2.5015	0.011577	141.3	69
505523	-4.5121	0.035196	76.66	79
505525	-3.45287	0.050425	37.2	80
505534	-3.73212	0.025282	102.31	77
505540	-5.00516	0.129467	1.03	63
505544	-2.51625	0.057258	183.36	74
505551	-5.495	0.129653	0	88
505557	-2.77056	0.052623	1.63	82
505559	-0.1564	0.071687	2.86	92
505560	-4.55234	0.021629	172.64	82

505576	-5.98893	0.012974	29.24	92
505594	-6.44037	0.009993	30.88	74
505597	-1.8104	0.073756	182.98	88

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63 Table S2: Tracer data for the post-flood survey (August 2014), in streamwise coordinates.

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Moose				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91806	0.601974	0.227178	2.85	86
91821	2.871856	0.281269	3.55	80
91823	2.306223	0.697678	18.28	100
91827	-0.84551	0.35514	3.41	101
91828	-0.02425	0.71253	19.98	102
91834	0.583336	0.380882	1.76	85
91835	1.66831	0.276569	3.15	79
91836	1.615959	0.482609	5.7	64
91841	0.992296	0.851753	23.7	92
91843	1.989558	0.721135	12.31	85
91849	-1.31499	0.238825	0	100
91859	0.636081	0.498689	9.8	98
91865	1.744002	0.103685	0.2	79
91868	1.778011	0.25578	3.74	56
91873	1.072474	0.397853	0.69	90
91874	1.027192	0.247978	0	86
91895	2.454466	0.456972	12.95	96
91903	-3.41045	0.331428	2.74	104
91907	-0.16547	0.36726	2.79	67
91908	0.197288	0.302249	0.71	108
91912	-2.68747	0.550476	11.15	81
91914	-0.75721	0.506689	6.67	127

91922	1.808993	0.68465	17.06	61
91928	-1.5435	0.675257	11.46	83
91931	1.667911	0.198675	0	116
91932	-0.1053	0.914411	24.5	72
91933	-0.97898	0.079295	0	126
91945	1.604199	0.783587	16.86	114
91947	1.688601	0.410456	4.01	63
91949	-1.96172	0.563625	12.6	84
91950	0.187565	0.815098	17.01	92
91956	-2.07867	0.418176	3.62	62
91965	0.712043	0.437291	7.83	119
91970	-0.4697	0.541317	12.97	76
91972	2.752764	0.260577	0.44	96
91995	0.6185	0.713173	14.53	106
92007	2.351152	0.654115	9.95	92
92020	2.845123	0.204469	0	106
92023	1.482014	0.437419	6.21	69
92052	-2.01123	0.555496	7.41	67
92053	0.677942	0.326055	7.38	67
92055	-0.00062	0.575345	14.39	85
92063	3.598813	0.205976	0	87
92066	0.859233	0.077075	0.41	84
92092	-1.32936	0.42577	3.53	88
92093	1.319496	0.500287	5.35	108
92095	1.876765	0.720987	12.77	70
92102	-0.48961	0.650137	13.2	98
505514	1.199647	0.518172	5.78	76
505528	1.628247	0.338038	1.36	73
505539	-1.69695	0.302284	3	73
505587	0.533919	0.713251	11.96	94
505596	3.779705	0.172641	0	61

Mart_Up				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91805	-2.67012	0.532026	6.23	109
91807	-1.5454	0.248957	3.42	73
91824	1.176049	0.151363	0	86
91825	-1.86494	0.34342	3.87	97
91837	-0.46368	0.303225	1.49	82
91844	-0.79895	0.283413	2.3	85
91846	1.899192	0.24342	2.82	80
91853	0.646989	0.243162	0.84	83
91864	1.542234	0.364074	0	94
91879	1.652831	0.218939	0	104
91891	-0.42149	0.175164	0.62	96
91897	-1.17287	0.366912	11	69
91900	1.539867	0.389085	3.83	100
91901	16.46413	0.450024	8.38	93
91906	-0.05385	0.351832	1.18	112
91911	1.348577	0.3001	1.91	91
91915	0.904341	0.21773	4.52	80
91934	-1.50947	0.307715	0.46	77
91943	-1.28823	0.299783	6.83	63
91953	0.658155	0.233209	1.54	99
91957	-1.90535	0.173499	0.38	85
91978	0.372552	0.314246	6.08	65
91999	-1.06494	0.156122	2.13	96
92008	0.560232	0.202021	1.69	72
92010	-0.10349	0.32826	5.44	72
92027	-3.42442	0.613511	20.67	83
92043	-1.36836	0.408041	5.48	71

92054	-1.787	0.116812	0	75
92078	-0.95759	0.417997	5.83	83
92082	0.387406	0.523928	4.98	73
92096	-1.03355	0.330753	0.26	70
505500	-0.40615	0.319965	6.39	51
505504	0.197872	0.509779	4.38	74
505508	-1.34828	0.275742	0.62	48
505512	0.244488	0.518699	7.7	89
505513	-0.72301	0.295129	0.55	83
505550	-1.71907	0.205525	0	61
505553	0.244521	0.165274	3.92	84
505568	-0.24867	0.413465	11.17	94
505573	-1.87059	0.487855	10.01	69
505586	-1.56466	0.264839	0	66
505598	0.124781	0.224827	0.79	75

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Control				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91812	6.152899	0.191931	0.74	112
91822	2.462612	0.527276	13.29	73
91838	-4.98584	0.201279	0	73
91842	1.041201	0.0867	1.64	106
91845	6.407009	0.114396	0.7	77
91847	-3.85995	0.147158	0.66	87
91848	-0.94239	0.335632	8.48	90
91854	-0.1903	0.171553	2.19	65
91862	0.098779	0.193794	4.71	63
91870	-3.23268	0.19744	2.03	113
91878	5.739473	0.016256	0.28	104
91881	5.017924	0.234806	2.9	99

91885	-3.00859	0.288811	8.19	80
91887	1.223251	0.548877	14.28	61
91888	0.350843	0.517616	16.69	84
91893	3.285862	0.358256	9.08	80
91898	4.530047	0.225793	4.94	70
91904	-4.45277	0.098717	0.37	84
91913	4.494201	0.034238	0.56	72
91916	-5.1585	0.214825	1.34	63
91921	0.515595	0.206296	0.68	86
91924	-3.5959	0.141774	1.1	83
91926	1.986783	0.310052	5.75	76
91930	-0.95288	0.210645	2.53	74
91946	-2.57959	0.172406	0	75
91959	-4.14603	0.107757	0.85	85
91960	-0.63046	0.207641	0.58	125
91964	-2.29162	0.209562	4.56	108
91977	3.456026	0.285124	9.41	90
91979	-1.29798	0.326581	11.04	95
91980	3.169387	0.391484	7.22	88
91991	-1.886	0.099962	0.64	93
91993	-0.11976	0.673878	22.39	101
92003	4.289914	0.138552	3.8	112
92004	3.128322	0.085974	2.71	88
92009	-2.79681	0.677817	18.51	62
92011	2.495787	0.292981	3.02	93
92012	2.223939	0.176324	2.9	90
92014	-0.75351	0.133866	0	83
92026	5.330655	0	0	106
92030	1.882828	0.23373	1.02	90
92032	-1.8694	0.207823	4.17	110
92036	5.150484	0.21656	0.44	80

92042	1.183814	0.426605	8.3	78
92046	-4.24076	0.149634	0	96
92048	3.560181	0.414974	9.78	80
92050	-1.88099	0.247147	2.95	84
92051	2.509387	0.194419	0.27	108
92057	-4.45354	0.207867	0.71	97
92076	1.078964	0.391424	11.17	79
92086	3.981884	0.231177	1.03	82
505403	2.146523	0.131299	1.14	119
505415	0.835739	0.060238	0.41	118
505426	3.333036	0.044088	0.68	116
505430	-0.85467	0.247707	4.72	111
505432	0.551824	0.344213	6.5	107
505444	0.825266	0.132987	0.85	110
505450	-4.42469	0.070335	0	136
505453	4.136018	0.150971	2.99	106
505462	-0.48355	0.386194	7.65	116
505464	-2.90396	0.143372	0.64	114
505476	-3.11514	0.222954	0.78	109
505477	-0.72183	0.211116	0	122
505480	1.720492	0.266637	8.22	105
505486	-1.63311	0.136953	3.08	127
505487	4.637177	0.257394	1.09	112
505501	-5.00945	0.28817	3.93	53
505507	4.26789	0.007312	0	83
505530	-3.56148	0.483445	10.43	80
505535	1.544195	0.482043	13.68	71
505536	2.102324	0.061891	1.17	87
505546	-2.19055	0.191615	0.38	86
505554	1.132209	0.48316	13.86	55
505555	-1.0187	0.277808	5.15	96

505562	4.763306	0.116832	0	90
505564	-4.85072	0.173506	0	63
505575	4.617116	0.058687	0	90
505577	-1.39283	0.08813	1.4	101
505578	2.966527	0.149385	2.7	88
505579	-3.40654	0.169933	0	95
505582	0.460377	0.706337	22.71	76
505592	5.683859	0.163536	3.09	71
505599	7.124538	0.188325	0.69	75

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Mart_Lo				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91975	-1.01262	0.094624	0.91	118
91976	0.202589	0.103828	0	92
91981	-0.28598	0.110862	0	118
91994	0.613938	0.136633	1.89	87
91997	0.241441	0.11314	4.74	91
92000	2.354542	0.092687	0.34	90
92001	-1.38505	0.170755	10.79	98
92017	0.822566	0.099194	0.53	73
92031	-0.57984	0.175746	14.52	70
92037	-1.38726	0.050862	0	85
92058	-0.1129	0.119293	10.13	75
92059	4.158253	0.148555	13.99	110
92060	1.241121	0.055706	0	134
92077	-0.86602	0.123422	1.14	77
92081	4.440621	0.081838	10.02	80
92084	1.694078	0.075307	7.67	101
92100	-0.8112	0.085883	1.04	110
92104	-3.35313	0.207493	29.42	106

505400	0.84564	0.121604	1.27	93
505401	-0.10687	0.117132	1.7	88
505402	-7.45387	0.346303	62.06	96
505404	-1.32896	0.28288	54.58	76
505405	2.556268	0.099554	0.88	116
505410	-2.61043	0.056871	0.38	91
505411	-1.86356	0.145503	11.27	78
505412	-3.67008	0.265719	37.73	80
505413	-2.71133	0.204488	21.2	106
505414	-2.38102	0.061304	4.03	75
505416	2.147443	0.121707	1.52	72
505417	-2.48134	0.068074	0	106
505419	1.068447	0.113188	0.43	113
505422	-2.77596	0.291015	39.52	96
505423	-0.59204	0.125709	1.87	95
505424	1.889603	0.06428	5.98	100
505425	0.497729	0.091431	0	69
505427	-1.94377	0.253473	30.24	81
505433	1.370718	0.13359	1.6	71
505435	-1.07167	0.154575	26.08	89
505436	-2.0197	0.27566	44.39	74
505439	0.458875	0.591862	132.93	80
505446	-2.73568	0.23734	38.46	97
505447	-2.04768	0.112627	0.59	89
505448	1.679667	0.125228	0	128
505449	3.405387	0.119896	1.67	76
505451	1.639874	0.122349	0.36	87
505454	-2.06168	0.081745	1.05	95
505455	-1.20968	0.041684	3.16	131
505457	1.428994	0.024218	1.7	89
505458	-0.6027	0.124435	0.33	90

505459	-3.76969	0.309898	59.75	99
505460	-0.37397	0.330188	50.68	88
505461	-2.48106	0.271265	36.94	102
505463	-2.06808	0.11419	0.3	88
505465	-3.08014	0.277741	38.12	80
505468	2.667812	0.022692	1.18	66
505471	0.092626	0.128336	0.89	123
505472	0.857588	0.049852	0	83
505473	1.10249	0.068379	2.9	89
505474	2.804395	0.142419	4.68	84
505475	-1.62913	0.194576	25.51	63
505478	0.04441	0.080737	1.92	97
505479	-0.84756	0.17737	11.93	92
505483	-1.58454	0.029287	1.83	125
505485	-1.35212	0.130816	0.58	87
505491	-3.67886	0.078868	1.13	120
505493	-0.83598	0.314472	70.05	80
505495	-1.87662	0.102246	0.25	117
505496	-2.07076	0.186764	20.67	87
505497	-0.06699	0.157672	33.15	77
505499	2.662159	0.125297	2.7	94
505543	-3.2148	0.267381	34.14	58

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EFB				
Tag ID	Npos	Spos	Dist	
			(m)	B (mm)
91810	-3.78155	0.48003	80.88	96
91819	-1.26452	0.912408	203.19	83
91830	-2.29594	0.202653	27.43	75
91832	-1.73855	0.201826	43.7	83
91851	0.132576	0.153474	29.27	64

91855	1.752536	0.169287	35.58	108
91856	-7.38944	0.127283	0.33	59
91860	-4.72881	0.131701	0.51	64
91867	-5.29001	0.037011	1.95	59
91875	-4.11973	0.469361	103.33	79
91876	-3.3138	0.67352	149.42	79
91884	0.112326	0.331554	64.59	112
91899	-33.3535	0.129576	26.46	70
91902	-6.90573	0.128788	0.21	112
91917	3.01387	0.229729	42.13	100
91920	-3.1314	0.123538	25.39	63
91925	-3.18007	0.12391	9.87	93
91938	-3.67849	0.060597	0.76	83
91940	-1.26584	0.365171	68.33	125
91942	-4.34989	0.087564	5.79	99
91952	-1.0323	0.102758	4.96	123
91955	-0.11431	0.150349	28.96	103
91961	2.230704	0.294212	62.1	79
91963	-1.7347	0.07204	3.45	87
91973	3.540759	0.280802	49.86	108
91985	4.478215	0.163577	19.16	113
91986	3.304107	0.19836	35.27	90
91987	0.784935	0.228608	44.33	98
91988	-3.26375	0.125186	0.3	108
91990	-5.09791	0.773685	159.55	73
91992	-5.97715	0.058932	1.98	115
91998	-4.87104	0.125135	0.51	136
92002	-3.41899	0.41957	89.39	76
92015	-5.15528	0.067737	6.05	83
92018	-0.52678	0.140814	24.67	77
92019	-1.96648	0.447528	98.72	99

92021	-2.10225	0.137718	11.9	76
92033	5.750483	0.170119	30.53	89
92038	-6.78632	0.124906	0	82
92040	2.97	0.955327	211.59	77
92041	-5.31266	0.098797	11.02	87
92061	-5.52654	0.134067	0.91	74
92065	-0.8655	0.882168	193.53	86
92071	2.218072	0.202745	40.72	102
92072	2.764937	0.239286	39.52	77
92074	-1.36613	0.430524	83.07	124
92075	2.683712	0.25722	52.05	84
92088	2.547975	0.411852	82.09	84
92094	3.224059	0.281218	46.07	81
92097	4.396074	0.26423	51.22	86
505420	0.942499	0.162574	18.32	89
505428	-7.5838	0.128126	0	116
505442	-5.6779	0.129467	0.5	134
505466	-3.68567	0.129719	0.32	129
505467	4.652453	0.296701	52.3	112
505482	-1.18707	0.166284	27.24	108
505484	-6.25292	0.124689	0.38	137
505489	5.215686	0.130333	11.76	144
505498	-2.88317	0.114874	6.69	100
505506	-2.7609	0.137961	25.81	77
505517	-3.78983	0.069896	0.97	90
505520	-0.04376	0.631583	141.3	69
505523	-1.94896	0.371565	76.66	79
505525	4.118827	0.213642	37.2	80
505534	-0.91969	0.474202	102.31	77
505540	-5.03026	0.13399	1.03	63
505544	-1.74971	0.861805	183.36	74

505551	-5.48459	0.129841	0	88
505557	-2.58061	0.059796	1.63	82
505559	-0.42922	0.084255	2.86	92
505560	-1.55062	0.779156	172.64	82
505576	-2.14563	0.141256	29.24	92
505594	-1.15703	0.145494	30.88	74
505597	-2.12039	0.876665	182.98	88

C: Summary of previous RFID tracer studies in gravel-bed rivers

Table S3: Previous experiments using RFID tracking technology in gravel-bed rivers.

Reference	Study Site	n	S (%)	D _{50b} (m)	D _{50t} (m)	# Events	Model Fitting
Nichols (2004)	Walnut Gulch	124	2.9-3.6	n/a	0.058	4	No
Lamarre et al. (2005)	Moras Creek	204	2.30	0.070	0.04- 0.25	2	No
Carre et al. (2007)	Nicolet River	110	n/a	0.090	0.64- 0.25	3	No
Lamarre and Roy (2008)	Spruce Creek	196	14.0	~0.09 0	0.086	5	No
Carmenen et al. (2010)	Arc River	300	0.2-1.0	n/a	n/a	3	No
Schneider et al. (2010)	Erlenbach Stream	495	17.0	n/a	n/a	8	No
MacVicar and Roy (2011)	Moras Creek	299	1.20	0.060	0.04- 0.36	5	No
Biron et al. (2012)	Nicolet River	169	0.150	0.039	0.05- 0.15	n/a	No
Bradley and Tucker (2012)	Halfmoon Creek	893	1.0	0.060	0.060	4	Yes, Gamma- Exponenti al
Houbrechts et al. (2012)	Aisne River	150 0	0.47	0.092	0.080	7	No
Liébault et al., 2012	Bouinec Torrent	451	1.60	0.020	0.053	3	Yes, Power- law
Phillips et al. (2013)	Mameyes River	300	0.78	0.120	0.125	6	Yes, Exponenti al

Milan (2013)	River Rede	98	0.60	0.081	0.078	8	No
Chapuis et al. (2015)	Durance River	232	0.23	0.040	0.049	1	No
Imhoff (2015)	E. Fork	428	1.5-2.9	~0.07	0.079	1	Yes
	Bitterroot			0			

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D: Analyses

D.1: Description of stochastic sediment transport models

The models we use to describe sediment dispersion describe probability distributions of step length and rest period for an ensemble of particle grains. By treating the number of steps taken by a particle as a discrete random variable, $N(t)$, the total displacement after an elapsed time $X(t)$ is:

$$X(t) = \sum_{i=1}^{N(t)} Y_i, t > 0 \quad (D1)$$

where Y_i denotes the length of each step and $X(t)$ the displacement of a grain after time t . Y_i is treated as a random variable. Considering the $N(t)$ as a random variable is equivalent to adding rests of a random duration between particle steps (Bradley and Tucker, 2012). In doing so, $N(t)$ follows a Poisson distribution with the probability mass function:

$$\Pr\{N(t)\} = \frac{(k_2)^n}{n!} e^{-k_2 t} \quad (D2)$$

where k_2 is a rate parameter associated with an exponentially distributed waiting time distribution. Because we assume the number of steps taken up to time t to be a Poisson process, the probability distribution of resting times between steps therefore has the density function:

$$p(t) = k_2 e^{-k_2 t} \quad (D3)$$

where $1/k_2$ is the average duration of a rest and its inverse (k_2) an entrainment probability. It is therefore assumed that step lengths and rest periods are random and are described by exponentially distributed distributions – a compound Poisson process. Both of the stochastic sediment transport models described herein assume a compound Poisson distribution of step length and rest period. The first is the Einstein-Hubbell-Sayre (EHS) model (Hubbell and Sayre,

1964), which predicts that a streamwise, one-dimensional probability density function (PDF) of tracers is:

$$f_t(x) = k_1 e^{-k_1 x - k_2 t} \sqrt{\frac{k_2 t}{k_1 x}} I_1(k_1 x k_2 t) \quad (D4)$$

where t is the time above the threshold for particle motion and I_1 a modified Bessel function of the first kind of order one. Multiplied by dx , this equation predicts the fraction of particles in a tracer population in the distance interval x to $x + dx$ at time t (Bradley and Tucker, 2012). The EHS model only applies when all particles in a population have taken at least one step, though the density function can be normalized by considering the fraction of the tracer population that remains at the origin:

$$f(0) = e^{-k_2 t} \quad (D5)$$

where $f(0)$ denotes the fraction of tracers remaining at the origin. Using this dispersion model requires estimates of mean particle step length and rest period, the latter of which is nearly impossible to measure in field settings but has been observed in a flume setting (Hubbell and Sayre, 1964). Because the distribution of step lengths is exponential, the fraction of tracers in successively farther-traveling bins decreases monotonically.

The second model we use is the Gamma-Exponential model (GEM; Yang and Sayre, 1971). It differs from the EHS model by applying a gamma distribution to step lengths instead of an exponential distribution, while continuing to assume exponentially distributed rest periods. The GEM has the PDF:

$$g_t(t) = k_1 e^{-k_1 x - k_2 t} \sum_{n=1}^{\infty} \frac{(k_1 x)^{nr-1}}{\Gamma(nr)} \frac{(k_2 t)^n}{n!} \quad (D6)$$

where r is the shape parameter of the gamma distribution of step lengths. Values of r can be any number greater than zero; we manually checked values between 0 and 5 to determining the best fit (after Bradley and Tucker, 2012).

The EHS model has three parameters: mean step length ($1/k_1$), mean resting time ($1/k_2$), and dispersion time (t). The GEM adds a fourth, a shape parameter (r) that affects the shape of the gamma distribution of step lengths in peak and rate of decay. The value of r is flexible and can be adjusted to peak or decrease faster than the exponential. The difference in how the EHS and GEM models treat the distribution of step lengths is the primary difference between the two.

Table S4: Einstein-Hubbell-Sayre (EHS) and Yang-Sayre (GEM) model parameters and R^2 values.

	EHS (Mueller)				GEM (Mueller)				
Study Reach	$1/k_1$ (m)	$1/k_2$ (hr)	t (hr)	R^2	$1/k_1$ (m)	$1/k_2$ (hr)	t (hr)	r	R^2
Moose Creek (U)	3.04	200	479	0.76	2.89	213	479	1.10	0.76
Martin Creek (U)	2.26	119	201	0.95	1.81	143	201	1.50	0.96
Control Reach	3.27	270	354	0.95	2.62	331	354	1.50	0.96
Martin Creek (L)	17.9	769	621	0.98	11.2	1050	621	2.20	0.98
East Fk. Bitterroot (L)	33.5	671	950	0.97	35.2	6350	950	0.90	0.97
	EHS (Recking)				GEM (Recking)				
Study Reach	$1/k_1$ (m)	$1/k_2$ (hr)	t (hr)	R^2	$1/k_1$ (m)	$1/k_2$ (hr)	t (hr)	r	R^2
Moose Creek (U)	3.04	10.7	26.0	0.75	3.03	11.6	26.0	1.20	0.76
Martin Creek (U)	2.26	27.0	45.5	0.95	1.87	32.2	45.5	1.50	0.96
Control Reach	3.27	97.1	128	0.95	2.52	123	128	1.60	0.96
Martin Creek (L)	17.9	500	113	0.98	11.2	192	113	2.20	0.98
East Fk. Bitterroot (L)	33.5	303	426	0.97	35.2	285	426	0.90	0.97

D.2: Estimates of critical Shields number

Below are the calculations used for the lower (Mueller) and upper (Recking) estimates of critical Shields number at each study reach – four confluence seed reaches (tributary and mainstem for each) and the control reach. We chose these two methods as they provide a bracket of the highest and lowest estimates of critical Shields number we could obtain from published literature in steep, gravel-bed systems similar to the study site. We assumed the true value to fall between these two estimates.

i). Mueller estimate

$$\tau_c^* \sim \tau_r^* = 2.18S + 0.021 \quad (D7)$$

Notation:

τ_c^* = Critical Shields number

τ_r^* = Reference dimensionless shear stress

S = Channel gradient

Mueller et al. (2005) define the reference dimensionless shear stress as the point where there is a very small, non-zero transport rate, a value that others (e.g., Bradley and Tucker, 2012) assume to be approximate of the true critical Shields number for coarse gravel and cobble particles. For each seed reach we measured the channel gradient of the thalweg during the initial bed topography survey. This gradient was input to the equation to produce Mueller estimates of critical Shields number:

i.1). Moose Creek (Upper confluence tributary)

$$\tau_c^* = 2.18(0.0185) + 0.021 = \mathbf{0.061}$$

i.2). Martin Creek (Upper confluence mainstem)

$$\tau_c^* = 2.18(0.029) + 0.021 = \mathbf{0.084}$$

i.3). Martin Creek (Control reach)

$$\tau_c^* = 2.18(0.0164) + 0.021 = \mathbf{0.057}$$

i.4). Martin Creek (Upper confluence tributary)

$$\tau_c^* = 2.18(0.0168) + 0.021 = \mathbf{0.057}$$

i.5). East Fork Bitterroot River (Upper confluence mainstem)

$$\tau_c^* = 2.18(0.0163) + 0.021 = \mathbf{0.056}$$

ii). *Recking estimate*

$$\tau_c^* \sim \tau_m^* = (5S + 0.06) \left(\frac{D_{84}}{D_{50}} \right)^{4.4\sqrt{S}-1.5} \quad (\text{D8})$$

Notation:

τ_c^* = Critical Shields number

τ_m^* = Mobility shear stress

S = Channel gradient

D_{84} = Particle b-axis size for which 84% of reach particles are smaller (m)

D_{50} = Median grain b-axis size (m)

Recking (2013) merged two asymptotic branches of a nonlinear relationship between grain size and critical Shields number to create a single continuous function that matches particle entrainment and sediment transport measurements. This work used a series of steep, mountainous streams to develop the relation, including Halfmoon Creek from Mueller et al. (2005). The relation only uses D_{50} , D_{84} , and S as inputs to estimate the reach-average threshold

of gravel entrainment using (Equation 12, Recking 2013), and we apply this equation to estimate the threshold of motion for the tracer particles:

i.1). Moose Creek (Upper confluence tributary)

$$\tau_c^* = (5(0.0185)) + 0.06 \left(\frac{0.10}{0.052} \right)^{4.4\sqrt{0.0185}-1.5} = \mathbf{0.084}$$

i.2). Martin Creek (Upper confluence mainstem)

$$\tau_c^* = (5(0.029)) + 0.06 \left(\frac{0.147}{0.064} \right)^{4.4\sqrt{0.029}-1.5} = \mathbf{0.109}$$

i.3). Martin Creek (Control reach)

$$\tau_c^* = (5(0.0164)) + 0.06 \left(\frac{0.125}{0.057} \right)^{4.4\sqrt{0.0164}-1.5} = \mathbf{0.068}$$

i.4). Martin Creek (Upper confluence tributary)

$$\tau_c^* = (5(0.0168)) + 0.06 \left(\frac{0.117}{0.068} \right)^{4.4\sqrt{0.0168}-1.5} = \mathbf{0.086}$$

i.5). East Fork Bitterroot River (Upper confluence mainstem)

$$\tau_c^* = (5(0.0163)) + 0.06 \left(\frac{0.137}{0.069} \right)^{4.4\sqrt{0.0163}-1.5} = \mathbf{0.074}$$

D.3: Dimensionless impulse (I*)

Our incipient motion estimates were paired with seed reach cross-sections and flow data through the calculation of the dimensionless impulse, I*. Given the two estimates of critical Shields

number for reach seed reach, we converted that value to an actual shear stress and identified the water surface elevations at each pressure transducer that correspond with the critical hydraulic radius (R_c) experiencing that shear stress. R_c was transformed to hydraulic radius using cross-sectional data, and used to calculate critical shear velocity values corresponding with incipient motion estimates.

At each seed reach the implanted pressure transducer measured water surface elevations at 30-minute (1800 second) intervals (“cells”). Integration of all cells where the shear velocity exceeded the critical shear velocity is the basis of the impulse calculation:

$$I^* = \int_{t_i}^{t_f} \frac{(U^* - U_c^*)dt}{D_{50}}, U^* > U_c^* \quad (D9)$$

Notation:

I^* = Critical Shields number

t_i = initial time above threshold

t_f = final time above threshold

U^* = shear velocity (m/s)

U_c^* = critical shear velocity (m/s)

D_{50} = Median grain b-axis size (m)

Once integration occurs, dt becomes t and the impulse becomes dimensionless. We avoided pure forward or backward numerical integration, at the recommendation of Phillips et al. (2013), and instead took the average of $(U^* - U_c^*)/D_{50}$ from two adjacent time cells and multiplying that by the time difference between them (1800 seconds). This is analogous to the trapezoidal rule.