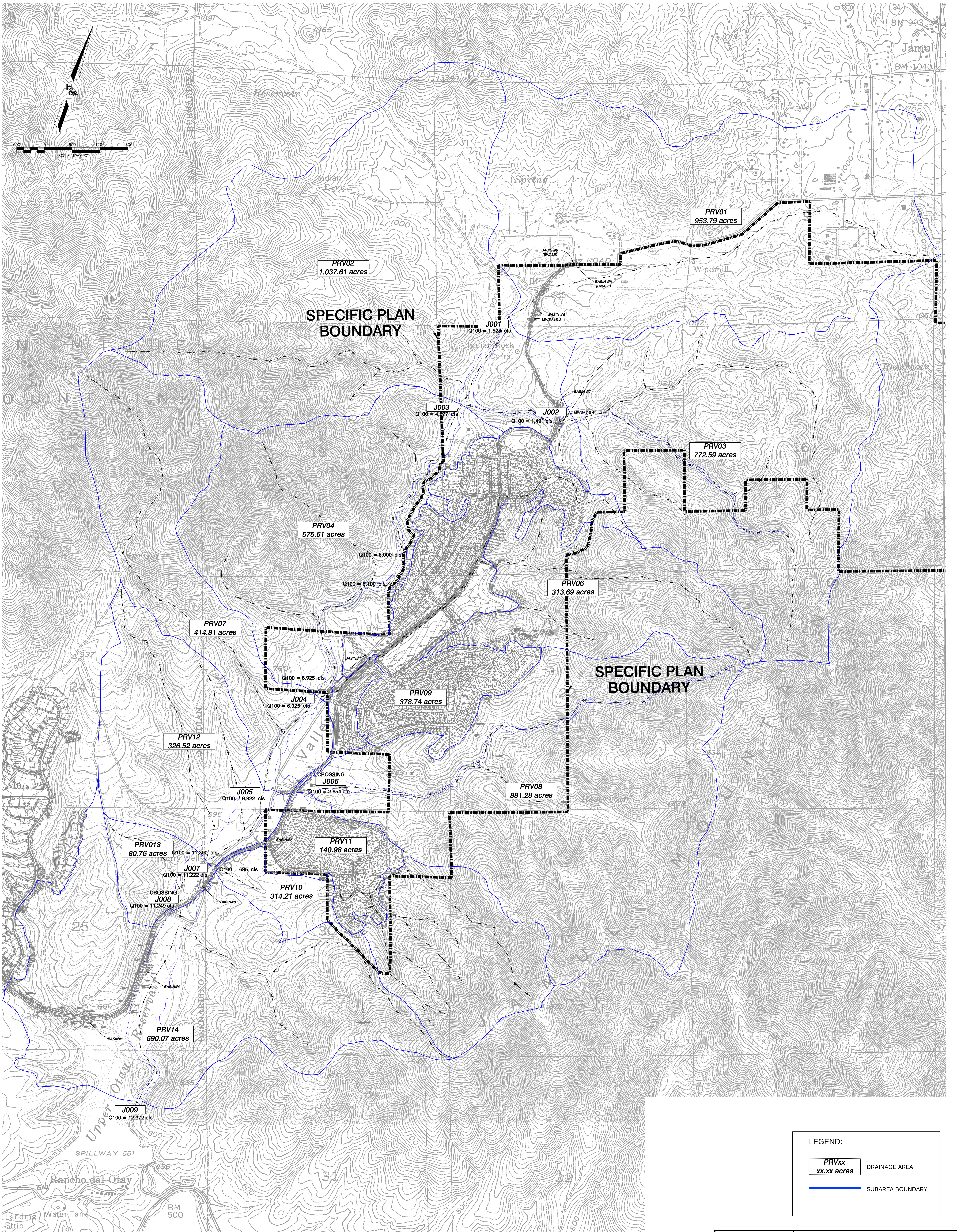

PREPARED BY:

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EXHIBIT 5.1

PROPOSED CONDITION HEC-HMS HYDROLOGY MAP

LAND EXCHANGE ALTERNATIVE

COUNTY OF SAN DIEGO, CALIFORNIA

W.O.# 2167-0127

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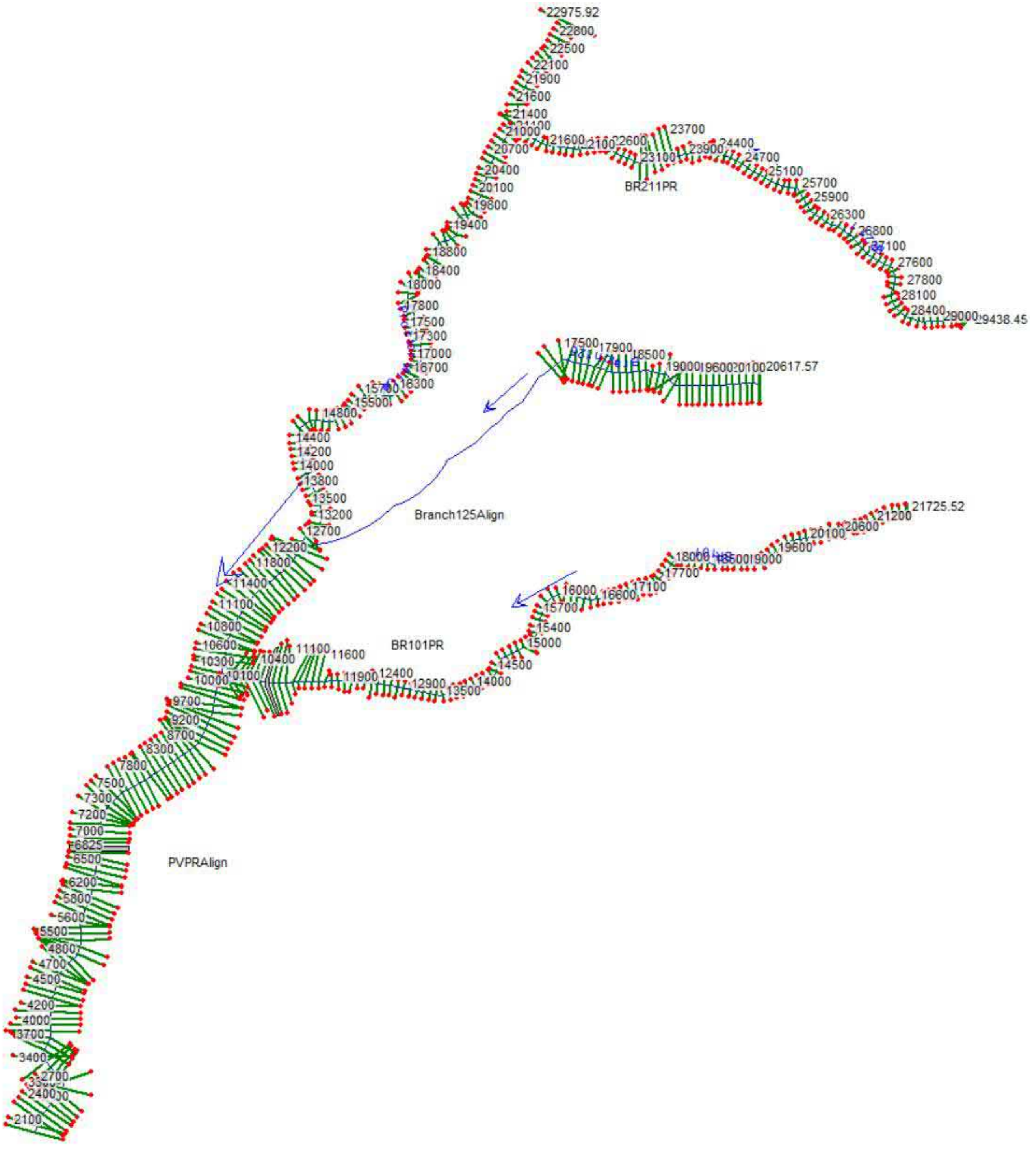
CHAPTER 6

Preliminary Hydraulic Analysis along Proctor Valley and Its Tributaries



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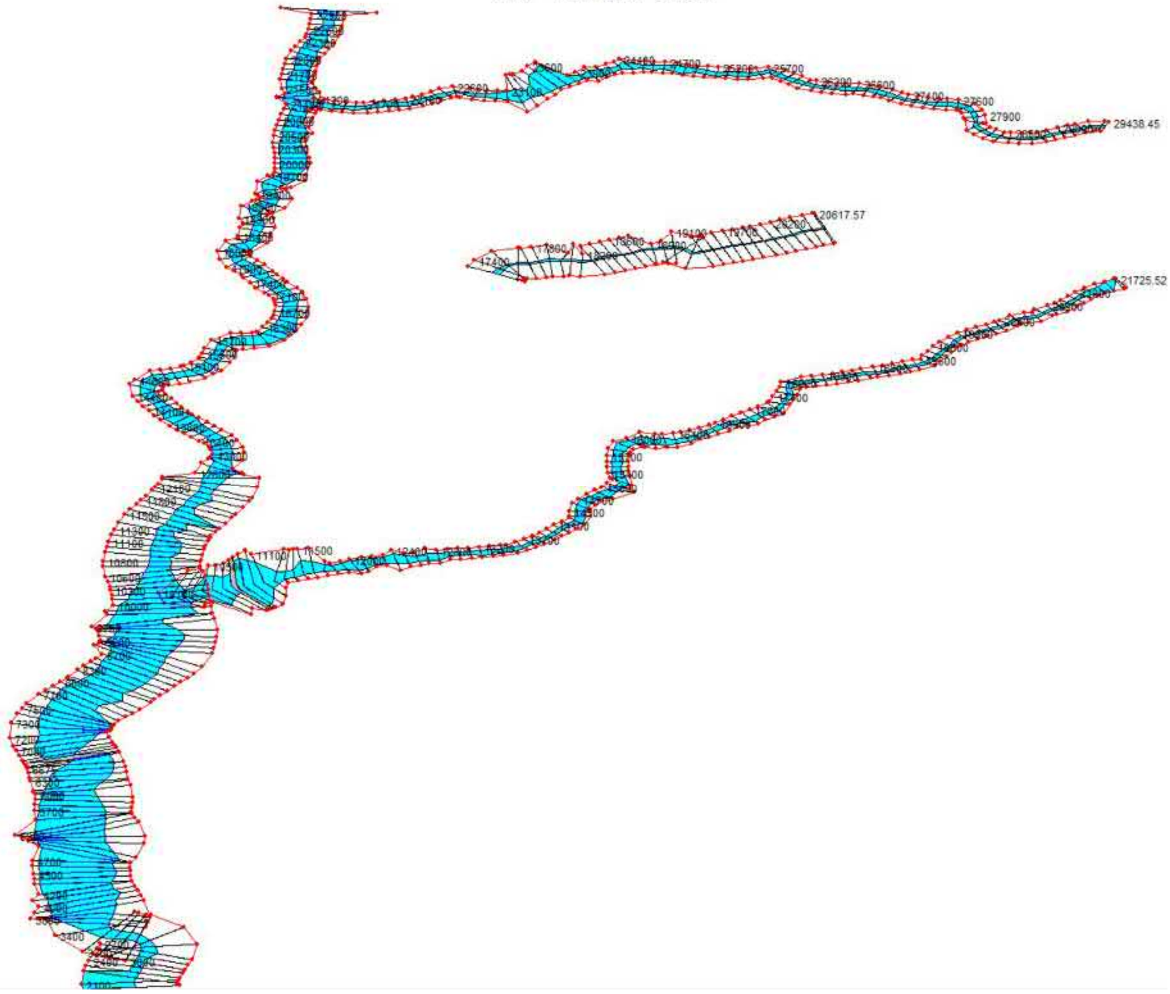
V14PR Plan: Plan 02 5/16/2017



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HEC-RAS Plan: Plan 02 Profile: PF 1

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Proctor Valley	PVPRAlign	22975.92	PF 1	4977.00	858.00	868.85		869.17	0.000777	4.55	1093.24	180.57	0.33
Proctor Valley	PVPRAlign	22900	PF 1	4977.00	858.40	868.81		869.11	0.000729	4.39	1133.04	184.75	0.31
Proctor Valley	PVPRAlign	22800	PF 1	4977.00	859.83	866.68	866.68	868.76	0.008307	11.57	430.31	103.72	1.00
Proctor Valley	PVPRAlign	22700	PF 1	4977.00	857.62	863.36	863.36	865.39	0.008478	11.43	435.36	108.66	1.01
Proctor Valley	PVPRAlign	22600	PF 1	4977.00	849.96	855.22	855.22	857.21	0.008423	11.31	440.14	111.18	1.00
Proctor Valley	PVPRAlign	22500	PF 1	4977.00	849.73	853.29	853.29	854.77	0.009164	9.78	508.74	171.09	1.00
Proctor Valley	PVPRAlign	22400	PF 1	4977.00	839.99	845.19	845.07	846.65	0.008106	9.72	512.19	158.73	0.95
Proctor Valley	PVPRAlign	22300	PF 1	4977.00	839.93	845.12		845.95	0.003574	7.31	681.24	175.05	0.65
Proctor Valley	PVPRAlign	22200	PF 1	4977.00	839.72	843.78	843.78	845.33	0.009120	10.00	497.66	161.43	1.00
Proctor Valley	PVPRAlign	22100	PF 1	4977.00	838.93	842.57	842.57	843.92	0.009652	9.30	535.02	202.14	1.01
Proctor Valley	PVPRAlign	22000	PF 1	4977.00	834.24	838.95	838.95	840.48	0.009082	9.91	502.42	164.87	1.00
Proctor Valley	PVPRAlign	21900	PF 1	4977.00	829.99	835.92	835.92	837.58	0.008854	10.33	481.80	145.41	1.00
Proctor Valley	PVPRAlign	21800	PF 1	4977.00	829.96	834.85	834.85	836.44	0.008969	10.13	491.08	154.14	1.00
Proctor Valley	PVPRAlign	21700	PF 1	4977.00	829.87	833.74	833.69	835.17	0.008877	9.62	517.33	174.38	0.98
Proctor Valley	PVPRAlign	21600	PF 1	4977.00	829.63	832.89	832.89	834.21	0.009674	9.23	539.04	206.28	1.01
Proctor Valley	PVPRAlign	21500	PF 1	4977.00	825.26	829.42	829.42	830.81	0.009534	9.47	525.62	191.61	1.01
Proctor Valley	PVPRAlign	21400	PF 1	4977.00	820.00	827.12		827.81	0.003219	6.68	744.94	202.68	0.61
Proctor Valley	PVPRAlign	21300	PF 1	4977.00	820.00	827.09		827.48	0.001965	5.00	994.64	288.66	0.48
Proctor Valley	PVPRAlign	21200	PF 1	4977.00	820.00	827.19		827.32	0.000416	2.86	1741.74	365.66	0.23
Proctor Valley	PVPRAlign	21100	PF 1	6000.00	820.00	827.03		827.26	0.000557	3.81	1574.48	262.37	0.27
Proctor Valley	PVPRAlign	21000	PF 1	6000.00	819.99	825.66		827.02	0.005361	9.37	640.65	153.56	0.81
Proctor Valley	PVPRAlign	20900	PF 1	6000.00	819.96	825.20		826.48	0.005000	9.06	662.54	158.45	0.78
Proctor Valley	PVPRAlign	20800	PF 1	6000.00	819.90	823.99	823.99	825.77	0.008774	10.72	559.84	158.59	1.01
Proctor Valley	PVPRAlign	20700	PF 1	6000.00	819.74	823.26	823.26	824.79	0.009197	9.93	604.43	199.43	1.01
Proctor Valley	PVPRAlign	20600	PF 1	6000.00	817.24	821.35	821.35	822.64	0.009577	9.13	657.21	253.95	1.00
Proctor Valley	PVPRAlign	20500	PF 1	6000.00	810.77	816.52	816.52	818.09	0.008979	10.08	595.19	188.66	1.00
Proctor Valley	PVPRAlign	20400	PF 1	6000.00	809.95	815.47	815.47	816.97	0.009197	9.82	610.78	205.03	1.00
Proctor Valley	PVPRAlign	20300	PF 1	6000.00	809.90	814.68		815.72	0.005561	8.16	735.22	223.51	0.79
Proctor Valley	PVPRAlign	20200	PF 1	6000.00	809.84	814.50		815.20	0.003249	6.70	895.09	244.18	0.62
Proctor Valley	PVPRAlign	20100	PF 1	6000.00	809.78	814.17		814.87	0.003243	6.71	894.00	242.99	0.62
Proctor Valley	PVPRAlign	20000	PF 1	6000.00	809.50	813.74		814.51	0.003801	7.06	850.44	241.63	0.66
Proctor Valley	PVPRAlign	19900	PF 1	6000.00	809.09	812.49	812.49	813.88	0.009528	9.46	634.32	231.41	1.01
Proctor Valley	PVPRAlign	19800	PF 1	6000.00	801.33	807.47	807.47	809.22	0.008678	10.63	564.69	161.03	1.00
Proctor Valley	PVPRAlign	19700	PF 1	6000.00	799.99	805.60		806.46	0.003619	7.44	806.57	203.83	0.66
Proctor Valley	PVPRAlign	19600	PF 1	6000.00	799.96	805.36		806.12	0.002696	6.98	860.04	191.25	0.58
Proctor Valley	PVPRAlign	19500	PF 1	6000.00	799.90	803.83	803.83	805.57	0.008832	10.59	566.51	164.21	1.01
Proctor Valley	PVPRAlign	19400	PF 1	6000.00	790.00	798.09	798.09	800.42	0.008052	12.25	489.72	105.27	1.00
Proctor Valley	PVPRAlign	19300	PF 1	6000.00	789.77	796.14	796.14	798.58	0.007926	12.51	479.45	98.52	1.00
Proctor Valley	PVPRAlign	19200	PF 1	6000.00	780.77	788.48	788.48	790.72	0.008127	11.99	500.30	112.10	1.00
Proctor Valley	PVPRAlign	19100	PF 1	6000.00	774.22	780.43	780.43	782.47	0.008500	11.46	523.56	130.60	1.01
Proctor Valley	PVPRAlign	19000	PF 1	6000.00	769.11	774.68	774.68	776.90	0.008262	11.95	502.16	114.45	1.01
Proctor Valley	PVPRAlign	18900	PF 1	6000.00	761.94	768.40	768.40	770.62	0.008251	11.97	501.42	114.36	1.01
Proctor Valley	PVPRAlign	18800	PF 1	6000.00	758.52	765.74	765.74	768.45	0.007889	13.21	454.26	84.82	1.01
Proctor Valley	PVPRAlign	18700	PF 1	6000.00	749.92	758.63	758.63	761.49	0.007694	13.55	442.85	77.64	1.00
Proctor Valley	PVPRAlign	18600	PF 1	6000.00	749.37	754.79	754.79	757.09	0.008121	12.15	493.79	107.84	1.00
Proctor Valley	PVPRAlign	18500	PF 1	6000.00	739.94	746.61	746.55	749.19	0.007656	12.88	465.68	88.43	0.99
Proctor Valley	PVPRAlign	18400	PF 1	6000.00	739.76	745.91	745.91	748.37	0.007948	12.59	476.55	96.77	1.00
Proctor Valley	PVPRAlign	18300	PF 1	6000.00	737.39	743.48	743.48	745.51	0.008344	11.43	524.99	129.74	1.00
Proctor Valley	PVPRAlign	18200	PF 1	6000.00	729.99	734.20	734.20	736.11	0.008522	11.07	541.94	142.37	1.00
Proctor Valley	PVPRAlign	18100	PF 1	6000.00	729.60	733.44	733.44	735.09	0.008996	10.31	581.75	177.73	1.01
Proctor Valley	PVPRAlign	18000	PF 1	6000.00	721.87	728.86	728.86	730.86	0.008458	11.34	529.26	134.01	1.01
Proctor Valley	PVPRAlign	17900	PF 1	6000.00	719.79	727.48	727.48	729.87	0.008103	12.39	484.37	103.10	1.01
Proctor Valley	PVPRAlign	17800	PF 1	6000.00	719.11	725.31	725.31	727.68	0.008108	12.33	486.63	104.25	1.01

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Proctor Valley	PVPRAlign	17700	PF 1	6000.00	718.46	724.62	724.62	726.78	0.008186	11.79	508.86	118.00	1.00
Proctor Valley	PVPRAlign	17600	PF 1	6000.00	709.62	714.78	714.78	716.91	0.008213	11.72	511.91	119.92	1.00
Proctor Valley	PVPRAlign	17500	PF 1	6000.00	707.33	712.47	712.47	714.27	0.008626	10.76	557.87	155.24	1.00
Proctor Valley	PVPRAlign	17400	PF 1	6000.00	699.97	706.22	706.22	708.39	0.008165	11.80	508.47	117.52	1.00
Proctor Valley	PVPRAlign	17300	PF 1	6000.00	699.84	705.24	704.87	706.97	0.006404	10.54	569.03	129.72	0.89
Proctor Valley	PVPRAlign	17200	PF 1	6000.00	699.37	704.97		706.29	0.004818	9.22	650.81	147.09	0.77
Proctor Valley	PVPRAlign	17100	PF 1	6100.00	698.19	703.69	703.69	705.60	0.008496	11.10	549.51	144.14	1.00
Proctor Valley	PVPRAlign	17000	PF 1	6100.00	690.00	698.51	698.51	700.67	0.008309	11.78	517.71	121.59	1.01
Proctor Valley	PVPRAlign	16900	PF 1	6100.00	689.92	696.49	696.49	698.51	0.008350	11.40	534.89	132.91	1.00
Proctor Valley	PVPRAlign	16800	PF 1	6100.00	689.59	695.20	695.20	697.24	0.008447	11.46	532.16	132.14	1.01
Proctor Valley	PVPRAlign	16700	PF 1	6100.00	689.18	694.79	694.34	696.32	0.006107	9.90	615.99	149.72	0.86
Proctor Valley	PVPRAlign	16600	PF 1	6100.00	688.78	693.79	693.79	695.56	0.008781	10.68	571.09	163.06	1.01
Proctor Valley	PVPRAlign	16500	PF 1	6100.00	688.38	693.02	692.94	694.56	0.008453	9.93	614.18	190.28	0.97
Proctor Valley	PVPRAlign	16400	PF 1	6100.00	687.97	692.20	692.20	693.64	0.009291	9.61	634.59	221.80	1.00
Proctor Valley	PVPRAlign	16300	PF 1	6100.00	686.19	690.61	690.61	692.08	0.009179	9.72	627.29	213.53	1.00
Proctor Valley	PVPRAlign	16200	PF 1	6925.00	679.99	687.56		688.46	0.003354	7.61	910.37	210.16	0.64
Proctor Valley	PVPRAlign	16100	PF 1	6925.00	679.97	687.34		688.15	0.002454	7.21	960.04	189.57	0.57
Proctor Valley	PVPRAlign	16000	PF 1	6925.00	679.88	687.20		687.92	0.001802	6.80	1017.65	173.06	0.49
Proctor Valley	PVPRAlign	15900	PF 1	6925.00	679.69	686.90		687.71	0.002060	7.24	957.13	163.70	0.53
Proctor Valley	PVPRAlign	15800	PF 1	6925.00	679.51	686.63		687.49	0.002335	7.46	928.42	167.19	0.56
Proctor Valley	PVPRAlign	15700	PF 1	6925.00	678.82	684.57	684.57	686.95	0.007992	12.37	559.65	117.63	1.00
Proctor Valley	PVPRAlign	15600	PF 1	6925.00	669.94	677.12	677.09	680.01	0.007523	13.65	507.17	86.43	0.99
Proctor Valley	PVPRAlign	15500	PF 1	6925.00	669.82	676.51	676.51	679.18	0.007841	13.10	528.74	100.31	1.01
Proctor Valley	PVPRAlign	15400	PF 1	6925.00	669.71	676.48		677.98	0.004176	9.81	705.71	129.43	0.74
Proctor Valley	PVPRAlign	15300	PF 1	6925.00	669.59	676.14		677.54	0.004039	9.49	729.60	137.48	0.73
Proctor Valley	PVPRAlign	15200	PF 1	6925.00	669.47	674.73	674.73	676.91	0.008239	11.83	585.47	135.81	1.00
Proctor Valley	PVPRAlign	15100	PF 1	6925.00	662.01	669.67	669.67	672.01	0.008147	12.26	564.82	122.93	1.01
Proctor Valley	PVPRAlign	15000	PF 1	6925.00	660.00	668.87		670.01	0.002542	8.55	809.59	125.03	0.59
Proctor Valley	PVPRAlign	14900	PF 1	6925.00	659.99	666.78	666.78	669.44	0.007804	13.09	528.88	99.73	1.00
Proctor Valley	PVPRAlign	14800	PF 1	6925.00	659.96	665.81	665.81	668.19	0.007958	12.37	559.60	117.86	1.00
Proctor Valley	PVPRAlign	14700	PF 1	6925.00	659.86	665.40		666.89	0.005258	9.80	706.43	155.49	0.81
Proctor Valley	PVPRAlign	14600	PF 1	6925.00	659.60	664.25	664.25	666.19	0.008422	11.18	619.58	159.63	1.00
Proctor Valley	PVPRAlign	14500	PF 1	6925.00	649.87	655.71	655.71	657.86	0.008282	11.77	588.19	138.45	1.01
Proctor Valley	PVPRAlign	14400	PF 1	6925.00	649.19	654.57	654.57	656.75	0.008148	11.82	585.78	134.90	1.00
Proctor Valley	PVPRAlign	14300	PF 1	6925.00	642.96	650.67	650.67	653.22	0.007952	12.80	541.10	108.00	1.01
Proctor Valley	PVPRAlign	14200	PF 1	6925.00	639.98	647.06	647.06	649.68	0.007841	12.98	533.42	102.96	1.01
Proctor Valley	PVPRAlign	14100	PF 1	6925.00	639.97	646.31	646.31	648.71	0.008018	12.44	556.82	117.19	1.01
Proctor Valley	PVPRAlign	14000	PF 1	6925.00	639.95	645.49	645.49	647.51	0.008345	11.40	607.56	151.20	1.00
Proctor Valley	PVPRAlign	13900	PF 1	6925.00	639.89	644.61		645.69	0.005056	8.33	831.10	227.89	0.77
Proctor Valley	PVPRAlign	13800	PF 1	6925.00	639.71	644.08	643.48	645.17	0.005342	8.38	826.67	234.33	0.79
Proctor Valley	PVPRAlign	13700	PF 1	6925.00	639.43	642.94	642.94	644.44	0.009301	9.80	706.52	239.91	1.01
Proctor Valley	PVPRAlign	13600	PF 1	6925.00	630.73	638.58		640.17	0.005546	10.12	684.62	149.75	0.83
Proctor Valley	PVPRAlign	13500	PF 1	6925.00	630.00	638.17		639.66	0.004099	9.80	706.42	128.31	0.74
Proctor Valley	PVPRAlign	13400	PF 1	6925.00	629.99	636.68	636.68	639.02	0.007987	12.28	564.13	120.92	1.00
Proctor Valley	PVPRAlign	13300	PF 1	6925.00	629.98	635.68	635.68	637.85	0.008249	11.83	585.50	136.23	1.01
Proctor Valley	PVPRAlign	13200	PF 1	6925.00	629.95	635.29		636.52	0.004937	8.89	778.63	189.50	0.77
Proctor Valley	PVPRAlign	13100	PF 1	6925.00	629.81	635.14		636.03	0.003057	7.56	916.10	198.28	0.62
Proctor Valley	PVPRAlign	13000	PF 1	6925.00	629.62	634.86		635.73	0.002915	7.49	924.83	193.37	0.60
Proctor Valley	PVPRAlign	12900	PF 1	6925.00	629.48	633.49	633.49	635.18	0.008820	10.43	664.19	196.62	1.00
Proctor Valley	PVPRAlign	12800	PF 1	6925.00	621.61	627.56	627.56	629.12	0.009578	10.01	691.66	228.13	1.01
Proctor Valley	PVPRAlign	12700	PF 1	6925.00	619.98	628.20		628.40	0.000427	3.64	1903.22	282.21	0.25
Proctor Valley	PVPRAlign	12600	PF 1	6925.00	619.94	628.10		628.35	0.000547	4.05	1709.85	259.43	0.28
Proctor Valley	PVPRAlign	12500	PF 1	9922.00	619.87	627.18		628.16	0.002550	7.94	1248.97	219.52	0.59

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Proctor Valley	PVPRAlign	12400	PF 1	9922.00	619.70	625.42	625.42	627.62	0.008072	11.89	834.32	190.22	1.00
Proctor Valley	PVPRAlign	12300	PF 1	9922.00	610.58	621.27	621.27	624.02	0.007696	13.30	746.27	137.29	1.01
Proctor Valley	PVPRAlign	12200	PF 1	9922.00	610.00	619.46	619.41	622.20	0.007455	13.28	746.88	134.74	0.99
Proctor Valley	PVPRAlign	12100	PF 1	9922.00	609.99	620.24		621.26	0.002626	8.12	1221.33	211.47	0.60
Proctor Valley	PVPRAlign	12000	PF 1	9922.00	609.97	619.20		620.89	0.003556	10.43	951.73	141.25	0.71
Proctor Valley	PVPRAlign	11900	PF 1	9922.00	609.91	617.35	617.35	620.27	0.007464	13.71	723.96	124.23	1.00
Proctor Valley	PVPRAlign	11800	PF 1	9922.00	609.80	616.35	616.01	618.26	0.006617	11.08	895.38	195.36	0.91
Proctor Valley	PVPRAlign	11700	PF 1	9922.00	609.69	615.90	615.90	617.32	0.009679	9.54	1040.32	377.93	1.01
Proctor Valley	PVPRAlign	11600	PF 1	9922.00	600.22	611.75	611.75	614.04	0.008150	12.13	817.91	180.91	1.01
Proctor Valley	PVPRAlign	11500	PF 1	9922.00	600.00	610.80	610.80	612.68	0.008711	11.01	900.83	242.35	1.01
Proctor Valley	PVPRAlign	11400	PF 1	9922.00	599.98	608.45	608.45	610.86	0.008016	12.46	796.59	168.15	1.01
Proctor Valley	PVPRAlign	11300	PF 1	9922.00	599.95	607.61	607.61	610.01	0.007929	12.44	797.48	166.61	1.00
Proctor Valley	PVPRAlign	11200	PF 1	9922.00	599.87	605.78	605.78	607.59	0.008748	10.78	920.57	257.81	1.01
Proctor Valley	PVPRAlign	11100	PF 1	9922.00	599.68	604.32	604.32	606.04	0.008747	10.50	944.96	276.14	1.00
Proctor Valley	PVPRAlign	11000	PF 1	9922.00	596.41	602.19	602.19	603.90	0.008898	10.51	943.71	278.63	1.01
Proctor Valley	PVPRAlign	10900	PF 1	9922.00	590.00	598.81	598.81	601.05	0.008192	12.01	826.37	186.01	1.00
Proctor Valley	PVPRAlign	10800	PF 1	9922.00	590.00	598.28		600.08	0.006478	10.74	923.88	206.75	0.90
Proctor Valley	PVPRAlign	10700	PF 1	9922.00	589.99	597.40	597.27	599.36	0.007745	11.22	883.93	212.86	0.97
Proctor Valley	PVPRAlign	10600	PF 1	9922.00	589.99	596.69	596.65	598.50	0.008516	10.81	917.49	251.59	1.00
Proctor Valley	PVPRAlign	10500	PF 1	9922.00	589.99	596.12	595.92	597.59	0.007708	9.72	1020.89	305.24	0.94
Proctor Valley	PVPRAlign	10400	PF 1	9922.00	589.98	595.37	595.27	596.76	0.008431	9.46	1049.39	349.88	0.96
Proctor Valley	PVPRAlign	10300	PF 1	9922.00	589.98	594.55	594.55	595.82	0.009674	9.03	1098.84	435.37	1.00
Proctor Valley	PVPRAlign	10200	PF 1	9922.00	589.97	594.15		594.70	0.003048	5.97	1662.55	515.48	0.59
Proctor Valley	PVPRAlign	10100	PF 1	11300.00	589.93	592.94	592.88	594.13	0.009127	8.77	1288.98	511.03	0.97
Proctor Valley	PVPRAlign	10000	PF 1	11300.00	589.30	592.07	592.07	593.11	0.010535	8.18	1381.79	677.21	1.01
Proctor Valley	PVPRAlign	9900	PF 1	11300.00	587.74	591.43		592.15	0.005931	6.82	1657.13	693.22	0.78
Proctor Valley	PVPRAlign	9800	PF 1	11300.00	586.50	590.41	590.41	591.35	0.010656	7.79	1450.01	770.39	1.00
Proctor Valley	PVPRAlign	9700	PF 1	11300.00	583.40	588.20	588.20	589.41	0.009855	8.82	1280.45	532.38	1.00
Proctor Valley	PVPRAlign	9600	PF 1	11300.00	581.34	585.57	585.57	586.90	0.009694	9.25	1222.26	468.00	1.01
Proctor Valley	PVPRAlign	9500	PF 1	11300.00	580.10	584.37		585.17	0.004943	7.19	1570.54	528.55	0.74
Proctor Valley	PVPRAlign	9400	PF 1	11300.00	579.95	584.09		584.68	0.003812	6.17	1830.92	638.45	0.64
Proctor Valley	PVPRAlign	9300	PF 1	11300.00	579.89	583.51		584.21	0.005415	6.75	1672.95	663.06	0.75
Proctor Valley	PVPRAlign	9200	PF 1	11300.00	579.52	582.79		583.60	0.006735	7.22	1565.22	661.17	0.83
Proctor Valley	PVPRAlign	9100	PF 1	11300.00	576.34	582.38		583.02	0.004281	6.41	1762.99	633.58	0.68
Proctor Valley	PVPRAlign	9000	PF 1	11300.00	573.98	581.15	581.15	582.33	0.010253	8.71	1296.72	564.39	1.01
Proctor Valley	PVPRAlign	8900	PF 1	11300.00	573.91	580.76		581.41	0.004056	6.48	1743.95	591.59	0.67
Proctor Valley	PVPRAlign	8800	PF 1	11300.00	571.98	579.53	579.53	580.74	0.010344	8.82	1280.67	550.40	1.02
Proctor Valley	PVPRAlign	8700	PF 1	11300.00	571.93	578.47	578.47	579.64	0.010220	8.67	1302.75	570.68	1.01
Proctor Valley	PVPRAlign	8600	PF 1	11300.00	571.89	577.83		578.70	0.006121	7.48	1510.87	562.71	0.80
Proctor Valley	PVPRAlign	8500	PF 1	11300.00	570.00	576.98	576.78	578.00	0.007854	8.11	1394.00	554.81	0.90
Proctor Valley	PVPRAlign	8400	PF 1	11300.00	569.99	576.18		577.25	0.007187	8.30	1361.66	489.44	0.88
Proctor Valley	PVPRAlign	8300	PF 1	11300.00	569.95	575.48	575.20	576.53	0.006971	8.23	1373.81	489.40	0.87
Proctor Valley	PVPRAlign	8200	PF 1	11300.00	569.86	574.38	574.38	575.70	0.009527	9.20	1228.12	467.30	1.00
Proctor Valley	PVPRAlign	8100	PF 1	11300.00	567.93	573.59	573.40	574.68	0.007932	8.38	1347.94	514.12	0.91
Proctor Valley	PVPRAlign	8000	PF 1	11249.00	567.76	572.57	572.57	573.79	0.009813	8.85	1270.82	523.86	1.00
Proctor Valley	PVPRAlign	7900	PF 1	11249.00	565.84	571.60	571.43	572.79	0.008106	8.74	1287.63	468.69	0.93
Proctor Valley	PVPRAlign	7800	PF 1	11249.00	565.61	570.86	570.64	572.01	0.007314	8.59	1310.24	452.94	0.89
Proctor Valley	PVPRAlign	7700	PF 1	11249.00	563.87	570.76		571.34	0.003645	6.12	1838.12	625.72	0.63
Proctor Valley	PVPRAlign	7600	PF 1	11249.00	563.66	570.64		571.02	0.001879	4.99	2256.32	635.95	0.47
Proctor Valley	PVPRAlign	7500	PF 1	11249.00	562.00	570.66		570.86	0.000702	3.55	3166.21	707.79	0.30
Proctor Valley	PVPRAlign	7400	PF 1	11249.00	561.99	570.66		570.79	0.000353	2.90	3873.38	699.45	0.22
Proctor Valley	PVPRAlign	7300	PF 1	11249.00	561.97	570.63		570.75	0.000317	2.84	3956.23	680.18	0.21
Proctor Valley	PVPRAlign	7200	PF 1	11249.00	560.39	570.62		570.72	0.000225	2.60	4328.36	658.18	0.18

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Proctor Valley	PVPRAlign	7100	PF 1	11249.00	559.97	570.60		570.70	0.000182	2.53	4452.79	604.85	0.16
Proctor Valley	PVPRAlign	7000	PF 1	11249.00	559.16	570.56		570.68	0.000206	2.72	4142.97	552.19	0.17
Proctor Valley	PVPRAlign	6900	PF 1	11249.00	557.99	570.45		570.64	0.000364	3.55	3170.75	433.31	0.23
Proctor Valley	PVPRAlign	6825	PF 1	11249.00	557.97	570.25	564.92	570.59	0.000586	4.62	2434.71	318.02	0.29
Proctor Valley	PVPRAlign	6750		Culvert									
Proctor Valley	PVPRAlign	6675	PF 1	11249.00	558.90	563.46	563.46	564.98	0.009092	9.89	1137.89	375.00	1.00
Proctor Valley	PVPRAlign	6600	PF 1	12372.00	557.93	562.26	562.26	563.69	0.009263	9.59	1290.11	451.69	1.00
Proctor Valley	PVPRAlign	6500	PF 1	12372.00	556.00	561.37	561.18	562.47	0.007709	8.41	1471.07	546.55	0.90
Proctor Valley	PVPRAlign	6400	PF 1	12372.00	553.99	560.79	560.43	561.71	0.006513	7.71	1605.47	599.28	0.83
Proctor Valley	PVPRAlign	6300	PF 1	12372.00	553.96	559.57	559.57	560.89	0.009597	9.21	1343.35	513.31	1.00
Proctor Valley	PVPRAlign	6200	PF 1	12372.00	553.62	558.47	558.47	559.76	0.009623	9.10	1359.18	529.69	1.00
Proctor Valley	PVPRAlign	6100	PF 1	12372.00	551.97	557.59	557.35	558.79	0.007352	8.80	1406.07	470.94	0.90
Proctor Valley	PVPRAlign	6000	PF 1	12372.00	551.73	557.02		558.06	0.006251	8.17	1513.99	501.29	0.83
Proctor Valley	PVPRAlign	5900	PF 1	12372.00	549.99	556.00	556.00	557.26	0.009872	9.03	1370.37	550.21	1.01
Proctor Valley	PVPRAlign	5800	PF 1	12372.00	549.94	555.07	555.01	556.21	0.009054	8.54	1448.46	593.22	0.96
Proctor Valley	PVPRAlign	5700	PF 1	12372.00	549.77	554.07	554.07	555.24	0.010269	8.68	1426.01	626.76	1.01
Proctor Valley	PVPRAlign	5600	PF 1	12372.00	547.94	552.32	552.32	553.45	0.010050	8.54	1449.39	642.55	1.00
Proctor Valley	PVPRAlign	5500	PF 1	12372.00	546.00	551.30	551.30	552.36	0.010344	8.26	1497.25	711.97	1.00
Proctor Valley	PVPRAlign	5400	PF 1	12372.00	545.99	550.72		551.47	0.005513	6.94	1782.26	686.26	0.76
Proctor Valley	PVPRAlign	5300	PF 1	12372.00	545.80	549.97		550.85	0.006825	7.52	1645.96	660.11	0.84
Proctor Valley	PVPRAlign	5200	PF 1	12372.00	543.88	549.38		550.20	0.005868	7.25	1706.78	644.90	0.79
Proctor Valley	PVPRAlign	5100	PF 1	12372.00	542.00	548.94		549.65	0.004628	6.74	1836.85	648.98	0.71
Proctor Valley	PVPRAlign	5000	PF 1	12372.00	541.89	548.19	547.95	549.04	0.007719	7.43	1664.12	743.98	0.88
Proctor Valley	PVPRAlign	4900	PF 1	12372.00	541.79	547.60		548.31	0.006227	6.74	1835.97	810.35	0.79
Proctor Valley	PVPRAlign	4800	PF 1	12372.00	541.21	546.86		547.65	0.006719	7.14	1731.56	741.19	0.82
Proctor Valley	PVPRAlign	4700	PF 1	12372.00	541.89	545.82	545.73	546.85	0.009250	8.12	1523.46	683.97	0.96
Proctor Valley	PVPRAlign	4600	PF 1	12372.00	541.81	544.91	544.82	545.92	0.009176	8.05	1536.47	694.82	0.95
Proctor Valley	PVPRAlign	4500	PF 1	12372.00	539.84	544.19	543.94	545.06	0.007375	7.49	1651.99	706.85	0.86
Proctor Valley	PVPRAlign	4400	PF 1	12372.00	539.41	543.45		544.33	0.007254	7.50	1649.94	696.13	0.86
Proctor Valley	PVPRAlign	4300	PF 1	12372.00	537.97	543.09		543.73	0.003997	6.41	1928.82	657.43	0.66
Proctor Valley	PVPRAlign	4200	PF 1	12372.00	537.84	542.89		543.37	0.002460	5.56	2226.73	654.54	0.53
Proctor Valley	PVPRAlign	4100	PF 1	12372.00	537.76	542.72		543.13	0.001937	5.15	2400.47	659.97	0.48
Proctor Valley	PVPRAlign	4000	PF 1	12372.00	535.98	542.64		542.94	0.001264	4.40	2814.24	712.99	0.39
Proctor Valley	PVPRAlign	3900	PF 1	12372.00	535.91	542.58		542.83	0.000815	4.00	3091.15	648.68	0.32
Proctor Valley	PVPRAlign	3800	PF 1	12372.00	535.66	542.55		542.75	0.000527	3.56	3471.57	625.29	0.27
Proctor Valley	PVPRAlign	3700	PF 1	12372.00	533.98	542.51		542.70	0.000455	3.50	3534.73	585.24	0.25
Proctor Valley	PVPRAlign	3600	PF 1	12372.00	533.80	542.44		542.65	0.000471	3.64	3395.61	542.97	0.26
Proctor Valley	PVPRAlign	3500	PF 1	12372.00	533.18	542.20		542.57	0.000896	4.89	2530.49	421.48	0.35
Proctor Valley	PVPRAlign	3400	PF 1	12372.00	531.95	541.55		542.40	0.001568	7.40	1672.39	226.30	0.48
Proctor Valley	PVPRAlign	3300	PF 1	12372.00	529.98	541.16		542.21	0.001844	8.23	1502.65	194.03	0.52
Proctor Valley	PVPRAlign	3200	PF 1	12372.00	529.92	540.94		542.04	0.001590	8.39	1475.49	164.93	0.49
Proctor Valley	PVPRAlign	3100	PF 1	12372.00	528.14	539.75		541.72	0.003432	11.28	1096.86	139.67	0.71
Proctor Valley	PVPRAlign	3000	PF 1	12372.00	527.98	537.84	537.84	541.11	0.007313	14.50	852.97	132.43	1.01
Proctor Valley	PVPRAlign	2900	PF 1	12372.00	527.94	536.63	536.63	540.00	0.007249	14.75	839.06	125.69	1.01
Proctor Valley	PVPRAlign	2800	PF 1	12372.00	526.83	536.18		538.24	0.003874	11.52	1074.28	146.11	0.75
Proctor Valley	PVPRAlign	2700	PF 1	12372.00	524.17	536.68		537.71	0.001400	8.16	1515.61	159.70	0.47
Proctor Valley	PVPRAlign	2600	PF 1	12372.00	523.98	534.82		537.34	0.003922	12.74	971.41	111.73	0.76
Proctor Valley	PVPRAlign	2500	PF 1	12372.00	521.66	532.42	532.42	536.66	0.007029	16.52	749.09	88.40	1.00
Proctor Valley	PVPRAlign	2400	PF 1	12372.00	519.95	530.37	530.37	534.36	0.007026	16.02	772.06	97.35	1.00
Proctor Valley	PVPRAlign	2300	PF 1	12372.00	519.41	529.70	529.70	533.55	0.007085	15.75	785.76	103.21	1.01
Proctor Valley	PVPRAlign	2200	PF 1	12372.00	517.78	528.22	528.22	531.43	0.007805	14.37	860.77	135.37	1.00
Proctor Valley	PVPRAlign	2100	PF 1	12372.00	514.96	521.49	520.93	523.49	0.005905	11.34	1090.97	202.86	0.86
Proctor Valley	PVPRAlign	2000	PF 1	12372.00	512.33	522.00	518.83	522.86	0.001747	7.42	1667.49	233.21	0.49

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
Branch125	Branch125Align	20617.57	PF 1	274.45	1149.51	1151.15	1151.14	1151.78	0.012297	6.37	43.07	33.98	1.00
Branch125	Branch125Align	20600	PF 1	274.45	1149.30	1150.94	1150.94	1151.55	0.012694	6.23	44.02	36.90	1.01
Branch125	Branch125Align	20500	PF 1	274.45	1139.16	1141.00	1141.00	1141.63	0.012515	6.37	43.07	34.57	1.01
Branch125	Branch125Align	20400	PF 1	274.45	1129.53	1132.52	1132.52	1133.40	0.011640	7.53	36.42	20.67	1.00
Branch125	Branch125Align	20300	PF 1	274.45	1125.81	1127.89	1127.89	1128.61	0.012208	6.78	40.46	28.66	1.01
Branch125	Branch125Align	20200	PF 1	274.45	1109.96	1113.96	1113.96	1115.08	0.012370	8.51	32.27	14.54	1.01
Branch125	Branch125Align	20100	PF 1	274.45	1109.02	1110.84	1110.84	1111.52	0.012485	6.62	41.45	30.88	1.01
Branch125	Branch125Align	20000	PF 1	274.45	1092.14	1095.46	1095.46	1096.51	0.011881	8.20	33.45	16.27	1.01
Branch125	Branch125Align	19900	PF 1	274.45	1078.89	1081.54	1081.54	1082.42	0.011797	7.55	36.35	20.92	1.01
Branch125	Branch125Align	19800	PF 1	274.45	1059.05	1061.40	1061.40	1062.26	0.011907	7.41	37.06	22.19	1.01
Branch125	Branch125Align	19700	PF 1	274.45	1042.71	1045.57	1045.57	1046.39	0.011797	7.24	37.89	23.27	1.00
Branch125	Branch125Align	19600	PF 1	274.45	1020.43	1024.26	1024.26	1025.41	0.012097	8.58	31.98	13.99	1.00
Branch125	Branch125Align	19500	PF 1	274.45	1009.07	1011.32	1011.32	1012.14	0.011916	7.29	37.66	23.22	1.01
Branch125	Branch125Align	19400	PF 1	274.45	989.82	993.14	993.14	994.19	0.011960	8.21	33.41	16.20	1.01
Branch125	Branch125Align	19300	PF 1	274.45	976.59	978.29	978.29	978.79	0.013630	5.71	48.05	48.54	1.01
Branch125	Branch125Align	19200	PF 1	274.45	965.00	966.62	966.62	967.18	0.013150	5.98	45.87	41.99	1.01
Branch125	Branch125Align	19100	PF 1	274.45	949.73	951.53	951.53	952.23	0.012216	6.70	40.94	29.74	1.01
Branch125	Branch125Align	19000	PF 1	274.45	939.43	941.71	941.71	942.51	0.011787	7.17	38.25	24.14	1.00
Branch125	Branch125Align	18900	PF 1	274.45	929.87	931.96	931.96	932.77	0.011861	7.24	37.92	23.58	1.01
Branch125	Branch125Align	18800	PF 1	274.45	913.28	916.71	916.71	917.65	0.011958	7.76	35.36	19.16	1.01
Branch125	Branch125Align	18700	PF 1	274.45	899.86	903.20	903.20	904.25	0.011966	8.19	33.52	16.40	1.01
Branch125	Branch125Align	18600	PF 1	274.45	879.92	882.58	882.58	883.55	0.011773	7.93	34.60	17.96	1.01
Branch125	Branch125Align	18500	PF 1	274.45	870.84	874.05	874.05	874.93	0.011718	7.51	36.54	20.87	1.00
Branch125	Branch125Align	18400	PF 1	274.45	858.41	860.24	860.24	860.85	0.012843	6.24	43.97	37.05	1.01
Branch125	Branch125Align	18300	PF 1	274.45	836.31	838.43	838.43	839.21	0.011944	7.07	38.83	25.32	1.01
Branch125	Branch125Align	18200	PF 1	274.45	829.34	830.90	830.90	831.50	0.012882	6.19	44.37	38.04	1.01
Branch125	Branch125Align	18100	PF 1	274.45	819.77	821.28	821.28	821.90	0.012572	6.31	43.47	35.47	1.01
Branch125	Branch125Align	18000	PF 1	274.45	814.76	816.64	816.64	817.19	0.013195	5.95	46.11	42.81	1.01
Branch125	Branch125Align	17900	PF 1	274.45	805.28	806.92	806.92	807.43	0.013560	5.69	48.20	48.91	1.01
Branch125	Branch125Align	17800	PF 1	274.45	783.04	785.57	785.57	786.42	0.011724	7.37	37.25	22.31	1.01
Branch125	Branch125Align	17700	PF 1	274.45	778.60	780.42	780.42	780.98	0.013241	6.00	45.73	42.07	1.01
Branch125	Branch125Align	17600	PF 1	274.45	769.62	771.50	771.50	772.20	0.012147	6.69	41.02	29.79	1.01
Branch125	Branch125Align	17500	PF 1	274.45	764.11	765.87	765.87	766.41	0.013249	5.89	46.61	44.14	1.01
Branch125	Branch125Align	17400	PF 1	274.45	759.47	760.54	760.54	760.94	0.014484	5.08	53.98	68.36	1.01
Branch125	Branch125Align	17300	PF 1	274.45	749.92	760.00	751.83	760.00	0.000011	0.52	523.45	90.26	0.04
BR211	BR211PR	29438.45	PF 1	1491.00	1299.58	1305.34	1305.34	1307.08	0.009241	10.57	141.10	40.71	1.00
BR211	BR211PR	29400	PF 1	1491.00	1289.70	1294.69	1294.69	1296.51	0.009353	10.83	137.73	38.26	1.01
BR211	BR211PR	29300	PF 1	1491.00	1269.29	1274.18	1274.18	1275.96	0.009359	10.70	139.40	39.78	1.01
BR211	BR211PR	29200	PF 1	1491.00	1258.82	1264.15	1264.15	1266.05	0.009262	11.06	134.83	35.66	1.00
BR211	BR211PR	29100	PF 1	1491.00	1248.86	1254.24	1254.24	1256.13	0.009318	11.05	134.94	35.93	1.01
BR211	BR211PR	29000	PF 1	1491.00	1239.34	1244.69	1244.69	1246.58	0.009238	11.03	135.24	35.82	1.00
BR211	BR211PR	28900	PF 1	1491.00	1219.88	1226.90	1226.90	1228.95	0.009554	11.49	129.77	32.10	1.01
BR211	BR211PR	28800	PF 1	1491.00	1197.26	1203.30	1203.30	1205.21	0.009294	11.07	134.65	35.36	1.00
BR211	BR211PR	28700	PF 1	1491.00	1175.68	1181.32	1181.32	1183.24	0.009347	11.10	134.28	35.52	1.01
BR211	BR211PR	28600	PF 1	1491.00	1155.28	1161.48	1161.48	1163.31	0.009278	10.85	137.39	37.59	1.00
BR211	BR211PR	28500	PF 1	1491.00	1139.69	1146.32	1146.32	1148.26	0.009318	11.18	133.39	34.37	1.00
BR211	BR211PR	28400	PF 1	1491.00	1121.24	1127.92	1127.92	1129.78	0.009271	10.91	136.61	36.92	1.00
BR211	BR211PR	28300	PF 1	1491.00	1109.60	1114.02	1114.02	1115.70	0.009367	10.38	143.58	43.30	1.01
BR211	BR211PR	28200	PF 1	1491.00	1099.49	1104.44	1104.44	1106.21	0.009355	10.69	139.45	39.83	1.01
BR211	BR211PR	28100	PF 1	1491.00	1089.98	1094.51	1094.51	1095.83	0.009730	9.23	161.45	61.08	1.00
BR211	BR211PR	28000	PF 1	1491.00	1079.95	1086.71	1086.71	1088.58	0.009495	10.98	135.82	36.99	1.01
BR211	BR211PR	27900	PF 1	1491.00	1079.75	1083.57	1083.57	1085.02	0.009574	9.69	153.95	53.31	1.00
BR211	BR211PR	27800	PF 1	1491.00	1073.32	1077.74	1077.74	1079.22	0.009434	9.78	152.51	51.53	1.00

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
BR211	BR211PR	27700	PF 1	1491.00	1069.29	1072.22	1072.22	1073.34	0.010344	8.49	175.63	79.79	1.01
BR211	BR211PR	27600	PF 1	1491.00	1059.99	1064.70	1064.70	1065.99	0.009973	9.12	163.45	64.53	1.01
BR211	BR211PR	27500	PF 1	1491.00	1059.74	1062.98		1063.76	0.005544	7.06	211.21	78.90	0.76
BR211	BR211PR	27400	PF 1	1491.00	1058.46	1061.81	1061.81	1062.99	0.010008	8.71	171.13	72.69	1.00
BR211	BR211PR	27300	PF 1	1491.00	1046.10	1051.40	1051.40	1052.82	0.009877	9.56	155.92	56.24	1.01
BR211	BR211PR	27200	PF 1	1491.00	1038.99	1042.58	1042.58	1043.96	0.009778	9.42	158.30	58.23	1.01
BR211	BR211PR	27100	PF 1	1491.00	1029.66	1034.27	1034.27	1035.95	0.009258	10.40	143.32	42.70	1.00
BR211	BR211PR	27000	PF 1	1491.00	1019.80	1023.01	1023.01	1024.36	0.009771	9.32	160.03	59.87	1.00
BR211	BR211PR	26900	PF 1	1491.00	1014.74	1018.56	1018.56	1019.62	0.010507	8.26	180.47	86.47	1.01
BR211	BR211PR	26800	PF 1	1491.00	1009.85	1012.31	1012.31	1013.41	0.010361	8.44	176.60	80.66	1.01
BR211	BR211PR	26700	PF 1	1491.00	999.93	1004.59	1004.59	1006.10	0.009530	9.87	150.99	50.60	1.01
BR211	BR211PR	26600	PF 1	1491.00	997.94	1002.33	1002.33	1003.78	0.009469	9.66	154.33	53.24	1.00
BR211	BR211PR	26500	PF 1	1491.00	995.16	998.74	998.74	1000.03	0.010025	9.09	164.11	64.84	1.01
BR211	BR211PR	26400	PF 1	1491.00	989.99	994.84	994.84	996.44	0.009332	10.14	147.01	46.11	1.00
BR211	BR211PR	26300	PF 1	1491.00	989.71	993.35	993.30	994.81	0.009039	9.70	153.78	50.32	0.98
BR211	BR211PR	26200	PF 1	1491.00	989.32	992.51	992.51	993.82	0.009940	9.20	162.09	62.57	1.01
BR211	BR211PR	26100	PF 1	1491.00	979.82	983.98	983.98	985.62	0.009319	10.27	145.12	44.28	1.00
BR211	BR211PR	26000	PF 1	1491.00	979.20	982.42	982.42	983.72	0.009942	9.14	163.10	63.64	1.01
BR211	BR211PR	25900	PF 1	1491.00	969.97	974.51	974.51	976.11	0.009295	10.14	147.10	46.08	1.00
BR211	BR211PR	25800	PF 1	1491.00	969.65	972.65	972.65	973.91	0.009969	9.01	165.41	66.29	1.01
BR211	BR211PR	25700	PF 1	1491.00	959.94	964.51		964.87	0.001723	4.81	309.92	85.35	0.45
BR211	BR211PR	25600	PF 1	1491.00	959.18	962.97	962.97	964.42	0.009631	9.66	154.41	53.94	1.01
BR211	BR211PR	25500	PF 1	1491.00	949.65	953.72	953.72	955.28	0.009348	10.02	148.86	47.75	1.00
BR211	BR211PR	25400	PF 1	1491.00	948.71	951.45	951.45	952.46	0.010704	8.06	184.95	93.29	1.01
BR211	BR211PR	25300	PF 1	1491.00	939.93	943.13		943.94	0.005499	7.20	207.18	74.40	0.76
BR211	BR211PR	25200	PF 1	1491.00	939.52	942.09	942.09	943.17	0.010442	8.34	178.72	83.75	1.01
BR211	BR211PR	25100	PF 1	1491.00	934.43	938.03	938.03	939.24	0.009933	8.83	168.93	69.80	1.00
BR211	BR211PR	25000	PF 1	1491.00	929.91	933.12	933.12	934.41	0.009897	9.13	163.35	63.94	1.01
BR211	BR211PR	24900	PF 1	1491.00	929.75	931.98		932.43	0.004797	5.42	275.10	137.94	0.68
BR211	BR211PR	24800	PF 1	1491.00	928.32	930.87	930.87	931.69	0.011471	7.26	205.51	128.09	1.01
BR211	BR211PR	24700	PF 1	1491.00	919.85	922.67	922.66	923.88	0.009984	8.81	169.18	70.33	1.00
BR211	BR211PR	24600	PF 1	1491.00	919.39	921.79	921.79	922.78	0.010735	7.97	187.07	96.12	1.01
BR211	BR211PR	24500	PF 1	1491.00	909.85	913.59	913.59	914.94	0.009610	9.30	160.29	59.63	1.00
BR211	BR211PR	24400	PF 1	1491.00	909.48	911.06	911.06	911.72	0.012129	6.52	228.73	174.89	1.00
BR211	BR211PR	24300	PF 1	1491.00	901.80	905.37	905.37	906.49	0.010114	8.50	175.49	78.33	1.00
BR211	BR211PR	24200	PF 1	1491.00	899.83	902.52	902.52	903.58	0.010419	8.26	180.59	86.13	1.01
BR211	BR211PR	24100	PF 1	1491.00	899.61	901.61	901.61	902.41	0.011413	7.21	206.71	129.67	1.01
BR211	BR211PR	24000	PF 1	1491.00	894.85	897.38	897.38	898.20	0.011454	7.28	204.80	127.06	1.01
BR211	BR211PR	23900	PF 1	1491.00	890.00	893.73	893.73	894.76	0.010365	8.16	182.72	88.37	1.00
BR211	BR211PR	23800	PF 1	1491.00	889.98	892.43	892.43	893.20	0.011420	7.03	212.13	138.45	1.00
BR211	BR211PR	23700	PF 1	1491.00	889.82	891.48		891.55	0.001022	2.12	702.57	452.63	0.30
BR211	BR211PR	23600	PF 1	1900.00	889.60	890.78	890.76	891.23	0.012580	5.35	355.12	375.65	0.97
BR211	BR211PR	23500	PF 1	1900.00	888.12	889.44	889.44	889.91	0.013663	5.55	342.58	365.31	1.01
BR211	BR211PR	23400	PF 1	1900.00	880.88	884.50		884.79	0.002618	4.25	446.63	205.16	0.51
BR211	BR211PR	23300	PF 1	1900.00	880.00	883.38	883.38	884.25	0.010933	7.51	253.11	144.88	1.00
BR211	BR211PR	23200	PF 1	1900.00	879.94	883.52		883.67	0.001142	3.06	621.04	251.15	0.34
BR211	BR211PR	23100	PF 1	1900.00	879.69	883.23		883.51	0.001855	4.22	449.99	161.05	0.45
BR211	BR211PR	23000	PF 1	1900.00	879.34	882.03	882.03	883.07	0.010478	8.16	232.85	113.66	1.01
BR211	BR211PR	22900	PF 1	1900.00	870.03	876.51	876.51	878.16	0.009145	10.30	184.51	56.07	1.00
BR211	BR211PR	22800	PF 1	1900.00	869.71	874.95	874.95	876.69	0.008995	10.59	179.34	51.42	1.00
BR211	BR211PR	22700	PF 1	1900.00	859.96	866.51	866.51	868.39	0.008984	11.01	172.61	45.95	1.00
BR211	BR211PR	22600	PF 1	1900.00	859.54	864.57	864.57	866.30	0.009046	10.54	180.21	52.27	1.00
BR211	BR211PR	22500	PF 1	1900.00	859.14	863.38	863.38	864.94	0.009208	10.01	189.75	60.90	1.00

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
BR211	BR211PR	22400	PF 1	1900.00	858.73	862.19	862.19	863.46	0.009908	9.05	210.00	83.79	1.01
BR211	BR211PR	22300	PF 1	1900.00	849.98	856.01	856.01	857.68	0.009147	10.37	183.26	55.06	1.00
BR211	BR211PR	22200	PF 1	1900.00	849.66	853.11	853.07	854.52	0.009153	9.51	199.86	69.18	0.99
BR211	BR211PR	22100	PF 1	1900.00	849.04	852.25	852.25	853.53	0.009913	9.07	209.50	83.25	1.01
BR211	BR211PR	22000	PF 1	1900.00	839.96	844.38	844.38	845.88	0.009421	9.83	193.28	65.20	1.01
BR211	BR211PR	21900	PF 1	1900.00	839.73	843.11	843.02	844.35	0.008890	8.93	212.80	79.74	0.96
BR211	BR211PR	21800	PF 1	1900.00	838.95	842.16	842.16	843.40	0.009971	8.92	212.96	87.20	1.01
BR211	BR211PR	21700	PF 1	1900.00	829.99	835.71	835.71	837.30	0.009240	10.11	187.92	59.21	1.00
BR211	BR211PR	21600	PF 1	1900.00	829.87	834.86		835.74	0.004212	7.52	252.64	69.19	0.69
BR211	BR211PR	21500	PF 1	1900.00	829.77	834.55		835.31	0.003709	6.98	272.18	76.15	0.65
BR211	BR211PR	21400	PF 1	1900.00	829.66	833.30	833.30	834.68	0.009649	9.44	201.25	73.71	1.01
BR211	BR211PR	21300	PF 1	1900.00	829.54	831.94	831.94	832.90	0.010657	7.88	241.06	125.67	1.00
BR211	BR211PR	21200	PF 1	1900.00	820.44	826.97		827.12	0.000733	3.13	607.51	169.10	0.29
BR211	BR211PR	21100	PF 1	1900.00	820.00	827.03	821.72	827.07	0.000086	1.52	1253.99	200.00	0.11
BR101	BR101PR	21725.52	PF 1	1726.00	1870.72	1881.44	1881.44	1884.15	0.013343	13.19	130.82	24.38	1.00
BR101	BR101PR	21700	PF 1	1726.00	1868.86	1879.98	1879.98	1882.72	0.013687	13.29	129.90	23.83	1.00
BR101	BR101PR	21600	PF 1	1726.00	1851.26	1856.45	1856.45	1857.15	0.012690	6.71	257.28	188.34	1.01
BR101	BR101PR	21500	PF 1	1726.00	1803.67	1806.91	1806.91	1807.78	0.011273	7.45	231.62	136.98	1.01
BR101	BR101PR	21400	PF 1	1726.00	1745.59	1748.80	1748.80	1749.80	0.010478	8.01	215.41	107.99	1.00
BR101	BR101PR	21300	PF 1	1726.00	1680.60	1685.90	1685.90	1687.55	0.009148	10.32	167.24	50.58	1.00
BR101	BR101PR	21200	PF 1	1726.00	1627.97	1633.57	1633.57	1635.43	0.009029	10.94	157.83	42.62	1.00
BR101	BR101PR	21100	PF 1	1726.00	1583.83	1591.10	1591.10	1593.12	0.009183	11.42	151.18	37.34	1.00
BR101	BR101PR	21000	PF 1	1726.00	1551.28	1557.63	1557.63	1559.42	0.009109	10.71	161.15	45.26	1.00
BR101	BR101PR	20900	PF 1	1726.00	1520.37	1527.03	1527.03	1528.88	0.009108	10.90	158.39	43.13	1.00
BR101	BR101PR	20800	PF 1	1726.00	1498.96	1504.53	1504.53	1506.22	0.009288	10.42	165.67	49.91	1.01
BR101	BR101PR	20700	PF 1	1726.00	1467.40	1473.69	1473.69	1475.58	0.009127	11.02	156.57	41.49	1.00
BR101	BR101PR	20600	PF 1	1726.00	1434.15	1441.66	1441.66	1443.78	0.009217	11.67	147.87	34.99	1.00
BR101	BR101PR	20500	PF 1	1726.00	1411.12	1418.64	1418.64	1420.76	0.009337	11.68	147.74	35.18	1.01
BR101	BR101PR	20400	PF 1	1726.00	1399.50	1405.36	1405.36	1407.41	0.009067	11.49	150.20	36.61	1.00
BR101	BR101PR	20300	PF 1	1726.00	1380.88	1387.94	1387.94	1389.93	0.009256	11.33	152.30	38.89	1.01
BR101	BR101PR	20200	PF 1	1726.00	1364.53	1372.32	1372.32	1374.25	0.009263	11.17	154.57	39.96	1.00
BR101	BR101PR	20100	PF 1	1726.00	1325.38	1333.19	1333.19	1335.45	0.009377	12.07	143.04	31.63	1.00
BR101	BR101PR	20000	PF 1	1726.00	1299.56	1307.55	1307.55	1309.94	0.009670	12.40	139.17	29.58	1.01
BR101	BR101PR	19900	PF 1	1726.00	1281.33	1288.33	1288.33	1290.45	0.009217	11.69	147.71	34.93	1.00
BR101	BR101PR	19800	PF 1	1726.00	1255.38	1259.82	1259.82	1261.48	0.009173	10.32	167.26	50.68	1.00
BR101	BR101PR	19700	PF 1	1726.00	1227.36	1233.09	1233.09	1234.97	0.009056	11.00	156.94	41.85	1.00
BR101	BR101PR	19600	PF 1	1726.00	1190.58	1197.97	1197.97	1199.92	0.009167	11.20	154.13	39.76	1.00
BR101	BR101PR	19500	PF 1	1726.00	1169.77	1176.39	1176.39	1178.30	0.009076	11.09	155.69	40.80	1.00
BR101	BR101PR	19400	PF 1	1726.00	1146.10	1151.91	1151.91	1153.77	0.009035	10.93	157.94	42.68	1.00
BR101	BR101PR	19300	PF 1	1726.00	1120.47	1125.90	1125.90	1127.36	0.009422	9.70	177.96	61.01	1.00
BR101	BR101PR	19200	PF 1	1726.00	1105.82	1110.95	1110.95	1112.73	0.009067	10.68	161.57	45.67	1.00
BR101	BR101PR	19100	PF 1	1726.00	1089.25	1094.64	1094.64	1096.56	0.009126	11.11	155.32	40.98	1.01
BR101	BR101PR	19000	PF 1	1726.00	1079.46	1084.79	1084.79	1086.69	0.009146	11.05	156.22	41.69	1.01
BR101	BR101PR	18900	PF 1	1726.00	1065.92	1070.87	1070.87	1072.62	0.009226	10.62	162.50	47.00	1.01
BR101	BR101PR	18800	PF 1	1726.00	1049.99	1056.59	1056.59	1058.44	0.009131	10.92	158.07	42.95	1.00
BR101	BR101PR	18700	PF 1	1726.00	1038.42	1043.76	1043.76	1045.27	0.009417	9.86	175.02	58.23	1.00
BR101	BR101PR	18600	PF 1	1726.00	1023.82	1029.35	1029.35	1030.97	0.009369	10.18	169.47	53.46	1.01
BR101	BR101PR	18500	PF 1	1726.00	1009.90	1015.43	1015.43	1017.15	0.009277	10.52	164.12	48.39	1.01
BR101	BR101PR	18400	PF 1	1726.00	999.90	1006.13	1006.13	1008.02	0.009076	11.04	156.37	41.44	1.00
BR101	BR101PR	18300	PF 1	1726.00	989.87	995.77	995.77	997.65	0.009245	11.01	156.77	42.28	1.01
BR101	BR101PR	18200	PF 1	1726.00	979.63	983.21	983.21	984.66	0.009576	9.68	178.37	62.07	1.01
BR101	BR101PR	18100	PF 1	1726.00	969.72	973.38	973.38	974.79	0.009586	9.54	181.01	64.64	1.00
BR101	BR101PR	18000	PF 1	1726.00	953.88	958.07	958.07	959.29	0.009868	8.89	194.13	79.13	1.00

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
BR101	BR101PR	17900	PF 1	1726.00	940.90	946.87	946.87	948.58	0.009165	10.49	164.49	48.36	1.00
BR101	BR101PR	17800	PF 1	1726.00	939.12	942.49	942.49	943.81	0.009834	9.19	187.72	72.38	1.01
BR101	BR101PR	17700	PF 1	1726.00	934.94	939.39	939.39	940.95	0.009243	10.02	172.20	55.18	1.00
BR101	BR101PR	17600	PF 1	1726.00	919.61	925.71	925.71	927.63	0.009031	11.10	155.46	40.62	1.00
BR101	BR101PR	17500	PF 1	1726.00	909.56	913.18	913.18	914.62	0.009566	9.65	178.93	62.64	1.01
BR101	BR101PR	17400	PF 1	1726.00	899.54	903.08	903.08	904.49	0.009490	9.53	181.21	64.28	1.00
BR101	BR101PR	17300	PF 1	1726.00	889.97	894.83	894.83	896.16	0.009759	9.25	186.57	70.49	1.00
BR101	BR101PR	17200	PF 1	1726.00	889.44	892.16	892.16	893.31	0.010278	8.60	200.66	88.54	1.01
BR101	BR101PR	17100	PF 1	1726.00	879.56	883.21	883.21	884.56	0.009751	9.32	185.17	69.66	1.01
BR101	BR101PR	17000	PF 1	1726.00	869.99	876.23	876.23	877.81	0.009309	10.11	170.74	53.87	1.00
BR101	BR101PR	16900	PF 1	1726.00	869.18	872.25	872.25	873.46	0.010073	8.83	195.55	81.96	1.01
BR101	BR101PR	16800	PF 1	1726.00	864.00	869.19	869.19	870.67	0.009429	9.74	177.16	60.46	1.00
BR101	BR101PR	16700	PF 1	1726.00	859.63	863.21	863.21	864.63	0.009476	9.54	180.93	64.03	1.00
BR101	BR101PR	16600	PF 1	1726.00	850.97	856.60	856.60	858.14	0.009362	9.95	173.50	56.81	1.00
BR101	BR101PR	16500	PF 1	1726.00	849.40	852.54	852.54	853.78	0.009967	8.93	193.34	79.05	1.01
BR101	BR101PR	16400	PF 1	1726.00	839.96	844.25	844.25	845.57	0.009663	9.21	187.32	71.25	1.00
BR101	BR101PR	16300	PF 1	1726.00	839.57	841.48	841.48	842.29	0.011401	7.23	238.60	148.82	1.01
BR101	BR101PR	16200	PF 1	1726.00	830.76	834.42	834.42	835.40	0.010546	7.96	216.78	110.38	1.00
BR101	BR101PR	16100	PF 1	1726.00	829.27	831.11	831.11	831.84	0.011770	6.86	251.63	174.32	1.01
BR101	BR101PR	16000	PF 1	1726.00	821.09	825.21	825.21	826.33	0.010085	8.50	202.97	90.40	1.00
BR101	BR101PR	15900	PF 1	1726.00	819.66	821.84	821.84	822.73	0.011083	7.54	229.04	131.63	1.01
BR101	BR101PR	15800	PF 1	1726.00	816.51	819.08	819.08	820.07	0.010729	7.95	217.21	112.43	1.01
BR101	BR101PR	15700	PF 1	1726.00	809.56	813.30	813.30	814.60	0.009832	9.15	188.71	73.66	1.01
BR101	BR101PR	15600	PF 1	1726.00	808.74	811.32	811.32	812.27	0.010896	7.80	221.16	118.95	1.01
BR101	BR101PR	15500	PF 1	1726.00	800.15	805.13	805.13	806.41	0.009720	9.08	190.18	74.31	1.00
BR101	BR101PR	15400	PF 1	1726.00	799.54	802.86		803.41	0.003977	5.94	290.61	110.30	0.65
BR101	BR101PR	15300	PF 1	1726.00	799.14	801.76	801.76	802.75	0.010630	7.99	215.90	109.87	1.01
BR101	BR101PR	15200	PF 1	1726.00	789.78	792.74	792.74	793.94	0.010092	8.78	196.52	83.08	1.01
BR101	BR101PR	15100	PF 1	1726.00	783.49	787.31	787.31	788.47	0.009988	8.67	199.13	85.46	1.00
BR101	BR101PR	15000	PF 1	1726.00	779.74	782.36	782.36	783.44	0.010407	8.34	206.91	97.07	1.01
BR101	BR101PR	14900	PF 1	1726.00	778.99	781.29	781.29	782.14	0.011315	7.39	233.69	140.39	1.01
BR101	BR101PR	14800	PF 1	1726.00	769.98	773.58	773.58	774.83	0.009895	9.00	191.88	77.20	1.01
BR101	BR101PR	14700	PF 1	1726.00	769.86	771.93	771.93	772.84	0.010963	7.65	225.54	125.47	1.01
BR101	BR101PR	14600	PF 1	1726.00	763.98	766.97	766.97	767.92	0.010966	7.82	220.75	118.96	1.01
BR101	BR101PR	14500	PF 1	1726.00	759.83	763.47		764.04	0.003583	6.10	283.05	95.19	0.62
BR101	BR101PR	14400	PF 1	1726.00	759.39	762.30	762.30	763.42	0.010275	8.51	202.72	91.32	1.01
BR101	BR101PR	14300	PF 1	1726.00	755.13	759.69	759.69	760.72	0.010302	8.14	212.13	102.54	1.00
BR101	BR101PR	14200	PF 1	1726.00	738.81	744.52	744.52	746.24	0.009214	10.53	163.94	48.20	1.01
BR101	BR101PR	14100	PF 1	1726.00	726.46	731.34	731.34	732.97	0.009391	10.24	168.50	52.37	1.01
BR101	BR101PR	14000	PF 1	1726.00	719.95	723.72	723.72	725.30	0.009410	10.10	170.95	54.65	1.01
BR101	BR101PR	13900	PF 1	1726.00	709.94	717.29	717.29	719.27	0.009154	11.29	152.90	38.68	1.00
BR101	BR101PR	13800	PF 1	1726.00	704.69	709.50	709.50	711.16	0.009222	10.34	166.90	50.19	1.00
BR101	BR101PR	13700	PF 1	1726.00	689.12	692.73	692.73	694.21	0.009433	9.77	176.60	59.50	1.00
BR101	BR101PR	13600	PF 1	1726.00	679.45	684.71	684.71	686.33	0.009224	10.23	168.75	51.95	1.00
BR101	BR101PR	13500	PF 1	1726.00	678.55	682.29	682.29	683.59	0.009664	9.16	188.43	72.29	1.00
BR101	BR101PR	13400	PF 1	1726.00	670.00	675.15	675.15	676.55	0.009709	9.47	182.20	66.52	1.01
BR101	BR101PR	13300	PF 1	1726.00	669.93	672.96	672.96	674.15	0.010055	8.76	197.05	83.62	1.01
BR101	BR101PR	13200	PF 1	1726.00	666.38	670.98	670.98	672.18	0.010259	8.79	196.46	84.03	1.01
BR101	BR101PR	13100	PF 1	1726.00	658.92	662.54	662.54	663.88	0.009599	9.29	185.72	69.23	1.00
BR101	BR101PR	13000	PF 1	1726.00	649.92	654.47	654.47	656.14	0.009279	10.36	166.57	50.59	1.01
BR101	BR101PR	12900	PF 1	1726.00	649.74	653.04	653.04	654.32	0.009847	9.09	189.91	74.87	1.01
BR101	BR101PR	12800	PF 1	1726.00	649.56	651.50	651.50	652.31	0.011396	7.24	238.32	148.44	1.01
BR101	BR101PR	12700	PF 1	1726.00	645.17	647.55	647.55	648.43	0.011050	7.52	229.41	131.83	1.01

HEC-RAS Plan: Plan 02 Profile: PF 1 (Continued)

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
BR101	BR101PR	12600	PF 1	1726.00	639.96	643.46	643.46	644.51	0.010311	8.22	209.89	99.93	1.00
BR101	BR101PR	12500	PF 1	1726.00	639.86	642.07	642.07	642.88	0.011477	7.21	239.51	151.02	1.01
BR101	BR101PR	12400	PF 1	1726.00	637.08	639.82	639.82	640.50	0.012049	6.65	259.67	191.99	1.01
BR101	BR101PR	12300	PF 1	1726.00	631.50	634.63	634.63	635.54	0.010742	7.69	224.58	122.41	1.00
BR101	BR101PR	12200	PF 1	1726.00	629.96	632.93	632.93	633.88	0.010830	7.80	221.22	118.58	1.01
BR101	BR101PR	12100	PF 1	1726.00	629.82	632.18		632.66	0.005558	5.53	312.21	170.20	0.72
BR101	BR101PR	12000	PF 1	1726.00	629.53	631.18	631.18	631.85	0.012170	6.54	263.73	201.06	1.01
BR101	BR101PR	11900	PF 1	1726.00	623.86	626.52	626.52	627.41	0.011004	7.55	228.46	130.14	1.01
BR101	BR101PR	11800	PF 1	1726.00	620.00	623.54	623.54	624.55	0.010441	8.06	214.12	106.22	1.00
BR101	BR101PR	11700	PF 1	1726.00	620.00	622.35	622.35	623.23	0.011091	7.53	229.13	131.81	1.01
BR101	BR101PR	11600	PF 1	1726.00	619.98	622.07		622.36	0.003496	4.34	397.83	220.35	0.57
BR101	BR101PR	11500	PF 1	1726.00	619.97	621.17	621.17	621.73	0.012893	5.97	289.04	264.11	1.01
BR101	BR101PR	11400	PF 1	1726.00	614.89	617.93	617.93	618.73	0.011508	7.18	240.39	152.91	1.01
BR101	BR101PR	11300	PF 1	1726.00	610.00	612.77	612.77	613.59	0.011431	7.30	236.54	146.09	1.01
BR101	BR101PR	11200	PF 1	1726.00	609.97	611.50		611.90	0.007169	5.09	338.99	253.33	0.78
BR101	BR101PR	11100	PF 1	1726.00	609.90	611.02		611.21	0.005538	3.50	492.61	531.48	0.64
BR101	BR101PR	11000	PF 1	1726.00	608.95	610.68		610.78	0.003116	2.52	684.31	785.39	0.48
BR101	BR101PR	10900	PF 1	1726.00	603.87	610.73	606.08	610.73	0.000045	0.65	2653.91	969.15	0.07
BR101	BR101PR	10800		Culvert									
BR101	BR101PR	10700	PF 1	1726.00	599.97	601.45		601.63	0.003460	3.41	506.85	401.02	0.53
BR101	BR101PR	10600	PF 1	1726.00	599.92	601.22		601.33	0.002283	2.65	650.37	547.57	0.43
BR101	BR101PR	10500	PF 1	1726.00	599.32	600.53	600.53	600.83	0.016348	4.44	388.56	661.43	1.02
BR101	BR101PR	10400	PF 1	1726.00	595.94	598.18	598.18	598.76	0.013113	6.09	283.41	254.66	1.02
BR101	BR101PR	10300	PF 1	1726.00	592.76	594.85	594.85	595.40	0.013288	5.90	292.39	278.06	1.01
BR101	BR101PR	10200	PF 1	1726.00	590.01	593.08		593.14	0.000586	1.97	874.31	413.66	0.24
BR101	BR101PR	10100	PF 1	1726.00	589.36	592.94	591.22	593.07	0.000783	2.84	607.05	200.00	0.29

CHAPTER 7

APPENDIX

CHAPTER 7

7.1. Reference Regarding Sediment Transport Capacity

Sediment Transport Capacity of Overland Flow

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P. Y. Julien, D. B. Simons

ABSTRACT

OVERLAND flow runoff can be either laminar or turbulent depending on the Reynolds number. The rate of soil erosion may be limited by the sediment transport capacity which depends on the type of flow. Sediment transport equations based on velocity were found to give different results than those based on shear stress. Most of the sediment transport equations developed for turbulent streams should not be applied to soil erosion by overland flow. A general relationship supported by dimensional analysis was derived. The recommended sediment transport capacity relationship can be written as a power function of slope and discharge and the range of exponents was defined from empirical relationships.

INTRODUCTION

Soil erosion by rainfall is one of the major hazards threatening the productivity of farmlands. The physical processes governing the movement of sediments by rainfall are very complex. The rate of soil erosion depends mainly on the detachment of soil particles and on the transporting capacity of overland runoff. Several sediment transport equations and soil loss relationships have been developed both from experimental studies in laboratories under simulated rainfall (Kilinc, 1972) and from statistical and regression analysis using field data (Wischmeier and Smith, 1978). Recently, some researchers have recommended the use of well-known bed-load equations to predict soil erosion losses from overland flow. For example, Komura (1976) used the Kalinske-Brown relationship and obtained fair agreement with observed data though his data set was relatively limited. The Meyer-Peter and Muller equation has also been suggested by Li (1979) for overland flow. Several sediment transport equations have been examined by Alonso, Neibling and Foster (1981) to determine how well they fit observed data on concave slopes.

Fundamental relationships for sediment transport in turbulent stream flows have been used as a basis for the analysis of sediment transport capacity by overland flow. However, since sheet flows are generally classified as laminar a theoretical analysis is required in order to determine if a sediment transport formula derived for turbulent streamflow is also applicable to laminar sheet flow.

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Therefore, the purpose of this study was to investigate the applicability of several sediment transport equations under various hydraulic conditions, including laminar sheet flow. In the first part of this paper, the hydraulic characteristics relevant to sediment transport are summarized to clearly point out the differences between turbulent and laminar flows. Then several sediment transport formulas valid for turbulent streamflow are examined under laminar sheet flow conditions. These transformed relationships are compared with regression equations obtained from experimental studies of soil erosion.

OVERLAND FLOW CHARACTERISTICS

In natural fields, overland flow occurs when the rainfall intensity is in excess of the infiltration rate of the soil. A very thin film of water covers the soil surface and it is referred to as the laminar sheet flow. As the runoff rate increases downslope, the flow converges into micro-scale channels called rills which gradually develop until they form large-scale channels called gullies. In a recent study, Thorne (1984) also defined ephemeral gullies in arable fields. These gullies are formed by the concentraiton of surface runoff and are obliterated each year by normal tillage.

Gully, rill and sheet runoff have different hydraulic properties depending on the relative magnitude of inertia and viscous forces. The ratio of these two types of forces defines the Reynolds number Re. When the inertia forces largely overcome the viscous forces, such as flows in rivers and gullies, the Reynolds number is large and the flow is turbulent. In the case of thin overland runoff, the viscous forces overcome the inertia forces and the flow is called laminar. In sheet flows, perturbations induced by raindrop impact and surface roughness are greatly attenuated due to the large magnitude of viscous forces at low Reynolds numbers. These forces damp out the velocity fluctuations caused by these disturbances and sheet flows over rough boundaries remain laminar until a critical value of the Reynolds number is exceeded.

Another major difference between stream flow and sheet flow is related to the flow depth. For a given particle size, the transport of sediments by saltation and suspension in overland flow is very limited due to the reduced flow depth. The bed load movement, however, may predominate and the most accurate sediment transport rates might be given by bed-load equations, the validity of this statement being precisely the purpose of this investigation.

The principal variables describing overland flow are shown in Fig. 1. The main geometric variables are slope length L and gradient S. The hydraulic variables are rainfall intensity i, flow depth h, mean velocity $\bar{u}$, unit water discharge q and thickness of the laminar sublayer δ'. The parameter generally associated with the sediment discharge q_s is bed shear stress τ_o; the other properties

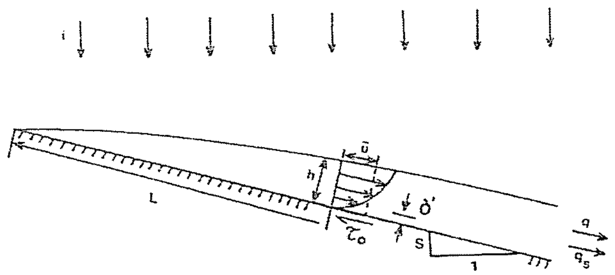

Fig. 1—Overland flow variables.

being gravitational acceleration g, kinematic viscosity ν and specific mass of water p.

Fundamental Equations

Two nonlinear partial differential equations derived by de Saint-Venant are generally used to solve the problem of gradually varied unsteady flows. These are the continuity relationship describing the conservation of mass and the momentum equation which is a force equilibrium relationship. In the case of steady overland flow, the continuity equation reduces to:

$$q = \bar{u}\, h \qquad [1]$$

Considering the principal terms of the momentum equation, the kinematic wave approximation has been recommended by Wooding (1965) and Woolhiser (1975). This approximation states that the slope of the energy line is equal to the soil surface slope, or:

$$S = S_f. \qquad [2]$$

in which S_f is the slope of the energy line or friction slope.

The slope of the energy line can be defined by the Darcy-Weisbach relationship:

$$S_f = \frac{f}{8}\,\frac{\bar{u}^2}{gh} \qquad [3]$$

where f is the Darcy-Weisbach friction factor.

The friction factor f is a function of the Reynolds number and the relative roughness for turbulent flows. The Reynolds number is defined as:

$$Re = \frac{\bar{u}\, h}{\nu} \qquad [4]$$

As the Reynolds number increases, the flow becomes turbulent and the friction factor is then a function of the roughness of the surface. The roughness of the boundary depends on the sediment size d_s and the thickness of the laminar sublayer δ'. Two important variables are associated with the thickness of the boundary sublayer δ'. These are bed shear stress τ_o and shear velocity U_*. These variables are defined as:

$$\tau_o = \rho g h S_f \qquad [5]$$

$$U_* = \sqrt{\frac{\tau_o}{\rho}} \qquad [6]$$

$$\delta' = \frac{11.6\,\nu}{U_*} \qquad [7]$$

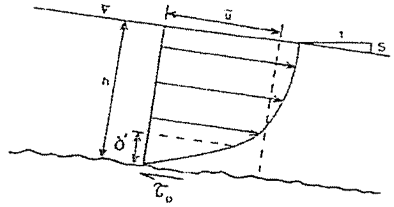

Fig. 2—Turbulent flow over a smooth surface.

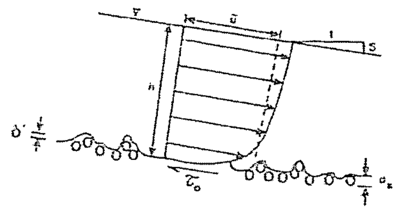

Fig. 3—Turbulent flow over a rough surface.

The ratio of sediment size d_s to the thickness of the laminar sublayer δ' delineates two types of turbulent flow conditions shown in Figs. 2 and 3 for smooth and rough boundaries respectively.

From combining equations [5], [6], and [7], the ratio δ'/d_s is:

$$\frac{\delta'}{d_s} = \frac{11.6\,\nu}{d_s\sqrt{ghS_f}} \qquad [8]$$

This parameter and the Reynolds number are used to define the type of overland flow.

Overland Flow Types

The four principal types of flow relevant to this investigation on soil erosion by overland flow are: (a) laminar sheet flow; (b) turbulent smooth flow governed by the Blasius equation; (c) turbulent rough flow (Manning equation); and (d) turbulent rough flow with very small relative roughness (Chézy equation). This last flow type is not very likely to occur in overland flow. However, it has been included in this analysis since it represents a limiting case for which the Darcy-Weisbach friction factor remains constant. For steady flow conditions, the principal variables related to soil erosion ($\bar{u}$, h and τ_o) are defined as a function of slope and water discharge.

Laminar Flow

In laminar flows with raindrop impact the Darcy-Weisbach friction factor f is related to: (a) the Reynolds number Re, (b) the surface friction coefficient k_o without raindrop impact, and (c) two empirical coefficients A and b for raindrop impact. The following relationship is generally used:

$$f = \frac{K}{Re} = \frac{k_o + Ai^b}{Re} \qquad [9]$$

The values of k_o have been tabulated by Woolhiser (1975) for various surface types and the value $k_o = 24$ is representative of the smooth surface condition. Experimental coefficients A and b have been obtained by Izzard (1944), Li (1972), and Fawkes (1972), and these

TABLE 1. RESISTANCE COEFFICIENTS A AND b FOR RAINFALL.

Reference	A†	b
Izzard (1944)	750	1.33
Li (1972)	118	0.4
Fawkes (1972)	393	1.0

†For i in m per hour.

values are indicated in Table 1. The experimental values of the friction coefficient f obtained by Shen and Li (1973) indicate that for a bare smooth surface, the flow is laminar for Re < 900 and the Blasius law is valid for turbulent smooth flows when Re > 2000. Chen's data (1976) show that k_o can be as large as 50,000 for vegetated surfaces and laminar flow conditions were observed for Reynolds numbers as large as 10^5.

At low Reynolds numbers, the friction parameter K for sheet flows is constant, and the Darcy-Weisbach equation is given by:

$$S_f = \left(\frac{K\nu}{\bar{u}\,h}\right)\frac{\bar{u}^2}{8gh} \quad \ldots\ldots [10]$$

The variables $\bar{u}$, h, and τ_o for laminar sheet flows derived from equations [1], [2], [5], and [10] are summarized in Table 2 for comparison with similar relationships valid under turbulent conditions.

Turbulent Flow over a Smooth Surface

For bare soil surfaces the flow becomes turbulent when Re > 2000 and the flow is called hydraulically smooth when the thickness of the laminar sublayer given by equation [7] is much in excess of the size of soil particles ($\delta' > 3\ d_s$). In this case, Keulegan (1938) derived an equation similar to the von Karman-Prandtl logarithmic equation. When the Reynolds number is not too large, this equation can be approximated by the Blasius equation for which the Darcy-Weisbach friction factor becomes:

$$f = \frac{0.316}{Re^{0.25}} \quad \ldots\ldots [11]$$

For turbulent flows over a smooth surface, the variables $\bar{u}$, h and τ_o given in Table 2 are derived from equations [1], [2], [3], [5], and [11]. The exponents of S for these three variables are identical to those obtained for laminar sheet flows.

Turbulent Flow over a Rough Surface

For turbulent flows an increase of the Reynolds number (or water discharge) raises the water level, and decreases the relative roughness and the friction factor. When the thickness of the laminar sublayer is small compared to sediment size ($\delta' < 5\ d_s$), the flow is hydraulically rough and the logarithmic equation given by Keulegan (1938) applies. The friction coefficient is defined as:

$$\sqrt{\frac{8g}{f}} = C = c_1 \log c_2 \frac{h}{d_s} \quad \ldots\ldots [12]$$

Approximate power relationships such as the Manning equation, however, are frequently used by hydraulic engineers. Since both equations give similar results for open channel flows without bedforms when the relative roughness ranges between 10 and 10000, the Manning equation (SI units) is used in this study. The equivalent Darcy-Weisbach f is then:

$$\sqrt{\frac{8g}{f}} = \frac{h^{1/6}}{n} \quad \ldots\ldots [13]$$

in which n is the Manning roughness coefficient. The well-known Manning-Strickler relationship gives the proportionality between the median size of the sediment particles (in mm) at the boundary and the Manning roughness coefficient:

$$n = 0.0132\, d_s^{1/6} \quad \ldots\ldots [14]$$

The combination of equations [1], [2], [3], [5], and [13] gives the relationships for $\bar{u}$, h, and τ_o shown in Table 2 for turbulent rough conditions (n = constant).

When the relative roughness becomes extremely small, the Darcy-Weisbach equation is equivalent to the Chézy equation ($f = 8g/C^2$). Both coefficients f and C are constant and after combining equations [1], [2], [3], and [5], the variables $\bar{u}$, h, and τ_o are written as a function of S and q. The resulting expressions are listed in Table 2. The relationship $\tau_o \propto \bar{u}^2$ is valid for the Chézy equation and the exponents are slightly different from those derived for the Manning relationship. The exponents of q and S of the velocity relationship are identical and equal to 0.333.

Discussion

The results of this analysis of the hydraulic characteristics are summarized in Table 2. The velocity, the flow depth, and the bed shear stress are written in

TABLE 2. SUMMARY OF FLOW CHARACTERISTICS (VELOCITY, DEPTH, AND SHEAR STRESS).

Velocity	$\bar{u} = c\, S^a\, q^d$		
Type of flow	c	a	d
Laminar (K = constant)	$\left(\frac{8g}{K\nu}\right)^{0.333}$	0.333	0.667
Turbulent, smooth boundary	$\left(\frac{8g}{0.316}\right)^{0.333} \quad -0.083$	0.333	0.417
Turbulent (n = constant)	$\left(\frac{1}{n}\right)^{0.6}$	0.3	0.4
Turbulent (f = constant)	$\left(\frac{8g}{f}\right)^{0.333}$	0.333	0.333
Depth	$h = c\, S^a\, q^d$		
Type of flow	c	a	d
Laminar (K = constant)	$\left(\frac{K\nu}{8g}\right)^{0.333}$	-0.333	0.333
Turbulent, smooth boundary	$\left(\frac{0.316}{8g}\right)^{0.333} \nu^{0.083}$	-0.333	0.583
Turbulent (n = constant)	$n^{0.6}$	-0.3	0.6
Turbulent (f = constant)	$\left(\frac{f}{8g}\right)^{0.333}$	-0.333	0.667
Shear stress	$\tau_o = c\, S^a\, q^d$		
Type of flow	c	a	d
Laminar (K = constant)	$\rho g \left(\frac{K\nu}{8g}\right)^{0.333}$	0.667	0.333
Turbulent, smooth boundary	$\rho g \left(\frac{0.316}{8g}\right)^{0.333} \nu^{0.083}$	0.667	0.583
Turbulent (n = constant)	$\rho g\, n^{0.6}$	0.7	0.6
Turbulent (f = constant)	$\rho g \left(\frac{f}{8g}\right)^{0.333}$	0.667	0.667

terms of discharge and slope. The exponent of the slope does not vary significantly for different flow conditions ranging from laminar to turbulent. The exponents of the slope for velocity, flow depth, and bed shear stress are respectively 0.33, −0.33, and 0.67. On the other hand, the exponents of the water discharge vary gradually and differ by a factor 2 between the extreme conditions. The exponents of discharge for velocity and shear stress vary in opposite directions. Indeed, for flow conditions changing from laminar to turbulent flows, the exponent of velocity varies gradually from 0.67 to 0.33 while the exponent of shear stress varies from 0.33 to 0.67. This effect is extremely important if we consider the rate of sediment transport.

SEDIMENT TRANSPORT EQUATIONS

The sediment transport capacity of overland flow under rainfall was investigated to obtain a theoretically sound relationship supported by empirical equations. The method of dimensional analysis was applied to the principal variables related to soil erosion.

Variables and Dimensional Analysis

Sheet erosion is the result of the detachment of soil particles by raindrop impact and transport by overland flow. The eroded soil particles are transported downstream by runoff and the unit sediment discharge is a function of the following variables:

$$q_s = f(L, S, i, \bar{u}, h, q, \tau_o, \tau_c, d_s, \rho_s, \rho, \nu, g) \quad \ldots\ldots [15]$$

in which τ_c is critical shear stress and d_s is size of soil particles, and the other variables are as defined previously. Among these variables, the first two (L, S) describe the geometry and the next five (i, $\bar{u}$, h, q, τ_o) are flow characteristics including rainfall intensity. The last six (τ_c, d_s, ρ_s, ρ, ν, g) are associated with soil and water properties and the gravitational acceleration. Shear stress is difficult to measure in the field and is usually computed from other variables. In a river, the variables S, $\bar{u}$, h, and q are used to describe stream flows because the velocity and depth are generally more easily measured than rainfall intensity i and runoff length L. For this reason, Laursen (1956) suggested the reduction of some sediment transport equations to a function of the variables $\bar{u}$ and h. In the case of soil erosion, however, the variables i and L have important physical significance. The slope and unit water discharge may be more easily measured than the velocity and depth. Therefore, the variables S and q may be more convenient than $\bar{u}$ and h as components of a sediment transport relationship for overland flow under steady-state condition; elimination of the variables $\bar{u}$ and h from the Darcy-Weisbach and the continuity equation $q = \bar{u}h$ is possible.

The critical shear stress value τ_c corresponds to the beginning of motion of the sediment particles. Its evaluation remains a complex problem requiring further investigation, but the fundamental relationship defining the incipient motion of sediments indicates that the critical shear stress is a function of the particle size and the specific masses of water and sediment. Therefore, the sediment size can be replaced by the critical shear stress in a sediment transport equation. The specific masses of water and sediment are nearly constant for particle sizes ranging from clays to gravels. In the case of aggregates, equivalent conditions of shear stress can be defined, for example, using an equivalent diameter, while keeping the same specific mass of sediment in the analysis.

Using these relationships and assuming ρ_s constant, equation [15] reduces to:

$$f(q_s, q, i, L, \rho, \nu, \tau_c/\tau_o, S) = 0 \quad \ldots\ldots [16]$$

The following Π-terms are obtained from dimensional analysis after L, ρ, and ν are selected as repeating variables:

$$f\left(\frac{q_s}{\rho\nu}, \frac{q}{\nu}, \frac{iL}{\nu}, \frac{\tau_c}{\tau_o}, S\right) = 0 \quad \ldots\ldots [17]$$

The sediment transport term can be written as a function of the product of the other Π-terms in the form:

$$\left(\frac{q_s}{\rho\nu}\right) = \bar{\alpha}\ S^{\beta}\left(\frac{q}{\nu}\right)^{\gamma}\left(\frac{iL}{\nu}\right)^{\delta}\left(1 - \frac{\tau_c}{\tau_o}\right)^{\epsilon} \ ;\text{for } \tau_o > \tau_c \quad \ldots\ldots [18]$$

In this equation, $\bar{\alpha}$, β, γ, δ, and ε are experimental coefficients and the sediment equations based on tractive force and stream power concepts are represents by the term $1 - (\tau_c/\tau_o)$.

Under dimensional form, this equation is transformed to:

$$q_s = \alpha\, S^{\beta}\, q^{\gamma}\, i^{\delta}\, \left(1 - \frac{\tau_c}{\tau_o}\right)^{\epsilon} \quad \ldots\ldots [19]$$

in which,

$$\alpha = \frac{\bar{\alpha}\rho L^{\delta}}{\nu^{\gamma+\delta-1}} \quad \ldots\ldots [20]$$

The derivation by Julien (1982) gives a general relationship between the sediment discharge and the dominant geometry and flow variables. The first three factors (S, q, i) represent the potential erosion or transport capacity by overland flow, which is reduced by the last factor reflecting the soil resistance to erosion. When τ_c remains small compared to τ_o, the equation for sediment transport capacity is:

$$q_s = \alpha\, S^{\beta}\, q^{\gamma}\, i^{\delta} \quad \ldots\ldots [21]$$

The sediment transport capacity by turbulent flows in deep channels is not a function of the rainfall intensity, and therefore, δ = 0 in this case.

Empirical Equations

Several empirical equations can be transformed to evaluate the coefficients α, β, γ, δ, and ε. Among the equations analyzed those proposed by Musgrave (1957), Li, Shen and Simons (1973), and Kilinc (1972) include tractive force, stream power, velocity, and discharge relationships. When the variables differ from those of equation [19], the relationships in Table 2 are used for the transformation of $\bar{u}$, h, and τ_o for laminar flows, while the Reynolds number is replaced by $Re = \bar{u}h/\nu$. The results summarized in Table 3 suggest that none of the actual equations is complete since some coefficients are still zero. Consequently, for each particular equation, the number of variables is reduced owing to

TABLE 3. TRANSFORMATION OF EMPIRICAL EROSION EQUATIONS FOR LAMINAR FLOW

$$q_s \sim S^{\beta} q^{\gamma} i^{\delta} \left(1 - \frac{\tau_c}{\tau_o}\right)^{\varepsilon}$$

Eq. No.	Reference	Equation	α†	β	γ	δ	ε
22	Musgrave (1947)	$q_s = \alpha' S^m L^n i^P$	α'	m	n	p-n	0
23	Zingg (1940)	$q_s \sim L^{1.66} S^{1.37}$	--	1.37	1.66	-1.66	--
24	Wischmeier and Smith (1978) (S>5%)	$q_s \sim L^{1.5} (.00076S^2 + .0053S + .0076)$	--	≅1.7	1.5	-1.5	--
25	Meyer and Monke (1965)	$q_s \sim L^{1.9} S_o^{3.5}$	--	3.5	1.9	-1.9	--
26	Young and Mutchler (1969)	$q_s \sim L^{2.24} S^{0.74}$	--	0.74	2.24	-2.24	--
27	Li et al. (1973)	$q_s = \alpha' \int_o^L \tau_o^2 \, dx$	$3\alpha' \frac{\gamma^2}{5}\left(\frac{K\nu}{8g}\right)^{2/3}$	1.33	1.67	-1	0
28	Komura (1983)	$q_s \sim q^{11/8} i^{1/2} S^{1.5}$	--	1.5	1.38	0.5	0
29	Kilinc (1972)	$q_s = e^{2.05}(\tau_o - \tau_c)^{2.78}$	$e^{2.05}\,\gamma^{2.78}\left(\frac{K\nu}{8g}\right)^{0.93}$	1.86	0.93	0	2.78
30	Kilinc (1972)	$q_s = e^{0.122}((\tau_o - \tau_c)\bar{u})^{1.67}$	$e^{0.122}\gamma^{1.67}$	1.67	1.67	0	1.67
31	Kilinc (1972)	$q_s = e^{-3.17}\bar{u}^{3.625}$	$e^{-3.17}\left(\frac{8g}{K\nu}\right)^{1.21}$	1.21	2.42	0	0
32	Kilinc (1972)	$q_s = e^{1.24}\bar{u}^{-4.67} Re^{-0.878}$	$e^{1.24}\nu^{0.878}\left(\frac{8g}{K\nu}\right)^{1.56}$	1.56	2.24	0	0
33	Kilinc (1972)	$q_s = e^{-11.6} Re^{2.05} S^{1.46}$	$e^{-11.6}\nu^{-2.05}$	1.46	2.05	0	0
34	Kilinc (1972)	$q_s = e^{11.7} q^{2.035} S^{1.66}$	$e^{11.7}$	1.66	2.03	0	0

†Sediment discharge in pounds per ft-s; multiply by 1.64×10^{-3} for q_s in tons/m·s.

these zero values. The most significant parameters pointed out in this analysis are the slope S and the discharge q. The numerical values of the coefficient β vary from 1.2 to 1.9, and γ, varies from 1.4 to 2.4. The variability of these exponents indicates the complexity of the sediment transport processes since only two major parameters are considered in this analysis. These relationships are in most cases particular to a study area or to the laboratory conditions under which the data were collected. Most equations include rill erosion which also influences the rate of soil erosion.

The well-known Universal Soil Loss Equation cannot be transformed directly into the general equation since the slope factor is written in a quadratic form. The equivalent exponent, however, is expected to vary between 1 and 2, and Julien (1982) found an equivalent exponent value near 1.7 while the discharge exponent 1.5 is an approximate value mostly valid when $S > 0.05$. The Kilinc and Richardson equations cannot define the parameters δ and ε since in their experiments, the soil surface was nearly impervious and also the bed tractive force was much in excess of the critical shear stress value. Throughout these transformations, the number of independent parameters remains the same. For example, equations [23], [25], and [26] based on slope and length have only two independent parameters because $\delta = -\gamma$. This remark is also valid for equations having one independent parameter since for equation [29] $\varepsilon = 3\gamma$ and $\beta = 2\gamma$; for equation [30] $\beta = \gamma = \varepsilon$; and for equation [31] $\beta = \gamma/_2$.

Further fundamental research is required to better define the exponents δ and ε. The coefficients of the general equation obtained by dimensional analysis are kept variable for the purpose of this study and equation [19] is recommended for watershed modeling. The prediction from each equation will be possible, provided the proper set of coefficients is selected from Table 3. Fair estimates can be obtained from a regression

TABLE 4. TRANSFORMED SEDIMENT TRANSPORT EQUATIONS FOR OVERLAND FLOW

$$q_s \sim s^{\beta} q^{\gamma} (1 - \frac{\tau_c}{\tau_o})^{\varepsilon}$$

Eq. No.	Investigator	Equation	Laminar				Turbulent: Smooth Boundary				Turbulent: Manning Equation				Turbulent: Chezy Equation			
			β	γ	ε	Index*	β	γ	ε	Index*	β	γ	ε	Index*	β	γ	ε	Index*
36	Du Boys	$q_s \sim \tau_o(\tau_o - \tau_c)$	1.33	0.66	1	1	1.33	1.17	1	1	1.4	1.2	1	1	1.33	1.33	1	1
37	WES	$q_s \sim (\tau_o - \tau_c)^{m=1.5}$	1	0.5	1.5	0	1	0.88	1.5	0	1.05	0.90	1.5	0	1	1	1.5	0
38	Shields	$q_s \sim Sq(\tau_o - \tau_c)$	1.67	1.33	1	1	1.67	1.58	1	2	1.7	1.6	1	2	1.67	1.67	1	2
39	Schoklitsch	$q_s \sim S^{1.5}(q - q_c)$	1.5	1	--	1	1.5	1	--	1	1.5	1	--	1	1.5	1	--	1
40	Kalinske-Brown	$q_s \sim \tau_o^{2.5}$	1.67	0.83	0	1	1.67	1.46	0	2	1.75	1.5	0	2	1.67	1.67	0	2
41	Meyer-Peter et al.	$q_s \sim (\tau_o - \tau_c)^{1.5}$	1	0.5	1.5	0	1	0.88	1.5	0	1.05	0.9	1.5	0	1	1	1.5	0
42	Bagnold	$q_s \sim \tau_o^{0.5}(\tau_o - \tau_c)$	1	0.5	1	0	1	0.88	1	0	1.05	0.9	1	0	1	1	1	0
43	Engelund-Hansen	$q_s \sim \tau_o^{1.5}\bar{u}^{2}$	1.67	1.83	0	2	1.67	1.71	0	2	1.65	1.7	0	2	1.67	1.67	0	2
44	Inglis-Lacey	$q_s \sim \bar{u}^{5} h^{-1}$	2	3	0	0	2	2.5	0	0	1.8	1.4	0	2	2	1	0	0
45	Yalin ($\tau_o \cong \tau_c$)	$q_s \sim \tau_o^{0.5}(\tau_o - \tau_c)^2$	1.67	0.83	2	1	1.67	1.46	2	2	1.75	1.5	2	2	1.67	1.67	2	2
46	Yalin ($\tau_o >> \tau_c$)	$q_s \sim \tau_o^{0.5}(\tau_o - \tau_c)$	1	0.5	1	0	1	0.88	1	0	1.05	0.9	1	0	1	1	1	0
47	Chang et al.	$q_s \sim \tau_o \bar{u}$	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0
48	Barekyan	$q_s \sim Sq\bar{u}$	1.33	1.67	0	2	1.33	1.42	0	2	1.3	1.4	0	2	1.33	1.33	0	1
49	Pedroli	$q_s \sim \tau_o^{1.6} h^{0.2}$	1	0.6	0	0	1	1.05	0	0	1.06	1.08	0	0	1	1.2	0	0

*The index represents the number of exponents within the ranges: $1.2 < \beta < 1.9$; and $1.4 < \gamma < 2.4$.

equation such as given by Kilinc (1972). For example, excellent results were obtained by Julien (1982) with the use of the discharge and slope formula (equation 34).

The formation of rills locally increases the unit water discharge q and the resulting erosion rate is expected to be larger than for uniform flow conditions. The rill erosion data collected by Kilinc were analyzed by Julien and Simons (1984) and once the volume of rill erosion was subtracted from the total erosion, the following regression equation was obtained:

$$q_s \sim S^{1.31}\, q^{1.93}\ ;\ (R^2 = 0.96) \qquad [35]$$

Both exponents for S and q are smaller than those for soil erosion including rills (equation [34]). This equation can be used for comparison with sediments transport equations for laminar sheet flow.

Applicability of Sediment Transport Equations for Turbulent Flows

Most of the well-known sediment transport equations originally derived for turbulent stream flows can be transformed to determine their applicability to natural conditions in overland flows.

This analysis included the transformation of the sediment transport equations suggested by Du Boys (1879), O'Brien-Rindlaub (1934), WES (1935), Shields (1936), Schoklitsch (1934), Kalinske-Brown (1949), Meyer-Peter and Müller (1948), Bagnold (1956), Engelund-Hansen (1967), Inglis-Lacey (1968), Yalin (1977), Chang et al. (1967), Barekyan (1962), and Pedroli (1963). The Einstein bedload equation has not been treated separately since it agreed very well with the Yalin and the Meyer-Peter and Müller equations.

The sediment transport capacity was investigated assuming that sediment size, fluid properties and gravitational acceleration were constant. Particular attention was focused at the values of β and γ which are the exponents of the slope and water discharge in equation 19. For each of the four types of flow described previously, the transformed relationships are summarized in Table 4 as follows: (a) laminar sheet flow; (b) turbulent flow over smooth surface as given by the Blasius equation; (c) turbulent flow described by the Manning equation; and (d) turbulent flow with constant Darcy-Weisbach friction factor f or Che'zy coefficient.

The last column for each type of flow represents an index of fitness of these basic equations with the observed value of exponents. This index is equal to the number of parameters (β, γ) enclosed within the ranges of empirical coefficients as determined in the previous section ($1.2 < \beta < 1.9$ and $1.4 < \gamma < 2.4$). The higher the index, the better this equation should compare with observed data. Conversely, when the index is equal to zero, the given equation is expected to be a poor relationship to predict the sediment transport capacity of overland flow.

The results in this table show that the exponents β of most relationships are within the range of observed values while the exponents γ are usually too small to fall within the range of empirical coefficients. These results were anticipated since it was demonstrated in the analysis of flow characteristics summarized in Table 2 that the exponent of slope remains constant while the exponent of discharge varies for different flow conditions.

CONCLUSIONS

This study points at the relationship existing between the mechanics of overland flow and soil erosion by rainfall. The authors address the problem of estimating the sediment transport capacity for rainfall erosion based on the mechanics of overland flow. The results of this study are of particular interest to:

1. soil scientists concerned with the decrease of productivity of agricultural land caused by rainfall erosion;
2. watershed modelers looking for a better sediment transport capacity relationship for mathematical simulation of erosion processes;
3. sedimentologists interested in the mechanics of sediment transport for both laminar and turbulent flows.

A general sediment transport relationship supported by dimensional analysis ($q_s \sim s^{\beta} q^{\gamma} i^{\delta}\ [1 - \tau_c/\tau_o]^{\epsilon}$) is recommended and the major conclusions of the study are summarized as follows: the analysis of overland flow characteristics encompasses a wide variety of flow conditions varying from laminar sheet flows on uniform soil surfaces to turbulent flows in rills and gullies. When the principal hydraulic variables of flow depth, velocity, and bed shear stress are written in terms of slope and discharge, the exponent of slope remains constant for these various types of flow. For different types of flow the exponents of discharge for the velocity and shear stress were shown to vary in opposite directions. Therefore, for predicting soil erosion the applicability of sediment transport relationships derived for turbulent flows depends on whether the sediment transport capacity is a function of velocity or shear stress.

Most of the sediment transport equations used for turbulent flow in streams should not be applied to rainfall erosion in laminar sheet flows. Among the equations examined, only those proposed by Engelund-Hansen and Barekyan seem relevant for predicting soil erosion losses by overland runoff. The formulas suggested by Shields, Kalinske-Brown and Yalin might also be considered though the exponent of discharge is clearly too small in the case of laminar sheet flow. The other equations generally underestimate the parameters β and γ and are irrelevant to predict rainfall erosion.

The range of values of the exponents of slope β and discharge γ were well-defined in this analysis of empirical relationships. The transformation of several sediment transport equations for overland flow can be summarized as follows: the empirical exponent β varies between 1.2 and 1.9 while the exponent γ ranges from 1.4 to 2.4. The variation of these exponents indicates the complexity of soil erosion processes and the specificity of each relationship for the site-specific conditions under which they were derived. Moreover, these exponents are function of the formation of rills and this study shows that both exponents β and γ of the sediment transport capacity relationship increase when the rills develop.

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LIST OF SYMBOLS

A	coefficient for raindrop impact
a, b, c, d	coefficients
r, r_1, r_2	constants
C	Chezy coefficient
d_s	size of sediment
f	Darcy-Weisbach friction factor
g	gravitational acceleration
h	flow depth
i	rainfall intensity
k_o	surface friction coefficient
K	friction parameter for laminar sheet flow
L	slope length
n	Manning coefficient
q	unit water discharge
q_c	critical unit water discharge
q_s	unit sediment discharge
R^2	coefficient of determination
S	slope
S_f	slope of the energy line
u	velocity at a distance y from the water surface
$\overline{u}$	mean velocity
U_*	shear velocity
$\alpha,\beta,\gamma,\delta,\varepsilon$	coefficients of the sediment transport equation
δ'	thickness of the laminar sublayer
γ	dynamic viscosity
ν	kinematic viscosity
ρ	specific mass of water
ρ_s	specific mass of sediments
τ_o	bed shear stress
τ_c	critical bed shear stress