Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes (Proceedings of a symposium held at Vienna, July 1998). IAHS Publ. no. 249, 1998.

Spatial and temporal variability in fractal dimensions of suspended solids in two southern Ontario rivers

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Abstract Flocculation affects the size, surface area, density and shape of fine-grained suspended solids in rivers which alters the transport properties of cohesive sediment. Factors controlling the shape of flocs include the source, size and geochemical characteristics of primary particles, varying degrees of chemical and biological coagulation in the water column as well as shear stress and turbulence levels in the stream. Floc shape can be quantified using fractal dimensions. This study examines spatial and temporal variability in fractal dimensions of suspended solids in two southern Ontario streams with contrasting riparian zones. Suspended solids were collected in triplicate at upstream and downstream sites in Strawberry Creek and Cedar Creek prior to snowmelt and during snowmelt. An image analysis system was used to determine area, longest axis and perimeter of particle populations. Fractal dimensions of the particle populations on each filter were calculated from the area-perimeter relationship (D) and the longest axis-area relationship (D_2). Temporal and spatial changes in the fractal dimensions were explained by the differences in land use and temporal changes in the contributions of various sediment sources. Implications of the study for modelling floc transport are discussed.

INTRODUCTION

Fluvial suspended sediment typically consists of a variety of complex, composite particles, usually referred to as flocs (e.g. Droppo and Ongley, 1989). Floc characteristics such as size, shape, density and settling velocity are controlled by the source, size and geochemical characteristics of primary particles, by the varying degrees of chemical and biological coagulation in the water column as well as by the shear stress and turbulence levels in the stream. Consequently, flocculation has important implications for erosion, transport and deposition of particles in aquatic systems. Crosby & De Boer (1995) found that changes in suspended sediment morphology reflected changes in sediment source contributions with basin scale.

In order to explain floc morphology in terms of modelling floc formation and the application of these models to drainage basin conditions in relation to particle size, density and settling velocity, it is necessary to develop rigorous methods which quantify the morphology of individual particles and particle populations. The objective of the project was to evaluate the fractal dimensions of fluvial suspended sediment in two streams with contrasting riparian zones and to relate spatial and temporal changes in fractal dimensions to changes in sediment source.

In this paper, the term "particles" describes composite rather than primary particles. Several methods have been developed to quantify the morphology of individual particles using fractal approaches (e.g. Mandelbrot, 1983; Whalley & Orford, 1989; Korvin, 1992). The present study follows the approach of Logan and co-workers (Logan & Wilkinson, 1990; Logan & Kilps, 1995; Kilps *et al.*, 1994) and others (e.g. Li & Ganczarczyk, 1989) who have been concerned with quantifying the morphology of particle populations using fractal dimensions. Suspended sediment particles, like many other natural objects, have been found to have area-perimeter relationships described by the power function:

$$P \propto A^{D/2} \qquad (1)$$

where P is the perimeter, A is the area and D is the fractal dimension of the collection. For Euclidean objects (e.g. squares and circles) $D = 1$. Values of D greater than 1, however, have been reported for synthetic fractals (Mandelbrot, 1983) and for a variety of natural objects such as clouds, lakes and snow patches during melt (e.g. Korvin, 1992). De Boer (1997) found that D ranged from 1.26 to 1.42 for suspended sediment particles during summer baseflow conditions, with the higher values reflecting the complex shapes of larger particles resulting from an algal bloom. The physical interpretation of $D > 1$ is that as objects become larger, i.e. as A increases, the perimeter increases more rapidly than for Euclidean objects so that the boundary becomes more convoluted.

The two-dimensional fractal dimension D_2 is determined using the power function

$$A \propto l^{D_2} \qquad (2)$$

where l is the maximum particle length and D_2 is the two-dimensional fractal dimension. For Euclidean objects $D_2 = 2$. Values of $D_2 < 2$ indicate that as object size increases the projected object area increases slower than the square of the length scale. This results from the fact that the projected area of larger objects is less than that of the Euclidean object of the same scale because of an increased elongation of the larger objects or because the larger objects surround or partially surround regions which are not part of the object. In the present study, both D and D_2 were calculated from the regression coefficients of the relevant variables.

STUDY SITES

Suspended solids were collected at upstream and downstream locations in two first order watersheds of the Grand River basin. The two streams, Strawberry Creek and Cedar Creek, differ in basin size, land use, Quaternary geology as well as in the extent and type of riparian vegetation. Strawberry Creek is located north of Maryhill, Ontario and drains an area of 2.7 km^2. Surface materials in the watershed consist of Port Stanley and Maryhill till complexes. Topography of the watershed is flat (avg. slope of 0.03) and land use is predominantly agriculture. Crops include soybeans, winter wheat and sweet corn. Strawberry Creek is typical of many rural watersheds in southern Ontario and has little or no stream riparian vegetation. Buffer strips typically 1 to 5 m in width border the edge of the stream. Sections of the creek have been straightened and excavated to more effectively drain adjacent fields and tile drains.

In contrast, Cedar Creek is considered the most significant cold water stream and fish habitat remaining in the Region of Waterloo. The creek is located near Ayr, Ontario and drains an area of approximately 50 km^2. The area is underlain by Wentworth till with surface deposits of outwash sands and gravels in the form of kames and eskers. Predominant land uses include aggregate extraction and some agriculture. The creek is bordered by an extensive riverine wooded shrub complex with concentrations of cedar and tamarack. Extensive riparian zones in this creek have significant potential to regulate the movement of materials in surface runoff and groundwater that flow from uplands to the stream.

METHODS

Suspended solids were collected in the centre of each stream on two dates at all four sites. On 7 March 1997, flow conditions were representative of discharge in between snowmelt events, with flows derived mainly from groundwater seepage and only in-channel sources contributing sediment. On 28 March 1997, flow conditions were typical of a snowmelt event with flow contributions from groundwater and overland flow generated by melting snow. On this day, suspended sediment was contributed by in-channel sources and by overland flow running directly into the channel.

Suspended solids were collected with sampling columns described by Droppo & Ongley (1992). The columns are 25 mm diameter Plexiglas tubes and depending on suspended solid concentrations a sample volume of 5, 10, 25 or 50 ml is used. The columns allow particles in the sample to settle onto a filter. When sediment concentrations are high, the smaller columns are used to prevent overlap of the deposited particles. Column volumes were selected in the field based on turbidity measurements (Model DRT-15B, HF Scientific turbidity meter) and calibration curves provided by Droppo & Ongley (1992). Suspended solids were collected using the sampling technique outlined by Droppo & Ongley (1992). Directly after sampling, the columns were placed on a 0.45 μm Millipore HA filter on a fritted glass filter holder. To speed up filtering, the sample in the column was filtered at low vacuum resulting in a filter with all particles in the column deposited in a 25 mm diameter spot. At each site, filters were prepared in triplicate and the replicates were taken sequentially within 5 min. Separate, depth-integrated samples for suspended sediment concentration were collected with a DH-48 sediment sampler.

In the laboratory, samples for suspended sediment concentration were filtered using 0.45 μm Millipore HA filters and vacuum filtration. Millipore filters prepared in the field were used for investigating fractal dimensions using an imaging system consisting of a Zeiss Jenamed II microscope with a Sony XC75 CCD camera linked to a Pentium computer running the Northern Exposure image analysis software. During analysis the Millipore HA filters were rendered semi-transparent by applying drops of low viscosity immersion oil ($n_D^{23°C} = 1.5150$) to the field of view. Images were collected using a 20× objective.

RESULTS AND DISCUSSION

The regression coefficients and the fractal dimensions in Tables 1 and 2 were calculated using only particles with a projected area greater than 4 μm² which corresponds to 16 pixels. This was done to avoid artefacts resulting: (a) from the algorithm used by Northern Exposure to calculate the particle perimeters, which underestimates the perimeters of small particles by a significant percentage; and (b) from the potentially large numbers of "particles" which are not true suspended sediment particles but instead represent background noise resulting from image processing. In terms of particle size fractions the 4 μm² cut-off roughly corresponds to the silt-clay boundary of 2 μm.

Because the fractal dimensions are calculated from regression coefficients, a direct comparison of the regression coefficients can be used to test for significant differences between samples using the t-statistic which is calculated as:

$$t = \frac{(b_1 - b_2)}{(S_{b_1}^2 - S_{b_2}^2)^{0.5}} \tag{3}$$

Table 1 Temporal and spatial changes in fractal dimension D.

Date	Replicate	Cedar Creek: upstream		downstream		Strawberry Creek: upstream		downstream		plume	
7 March	1	1.22	0.01*	1.21	0.01	1.23	0.01*	1.24	0.00*		
	2	1.23	0.00*	1.24	0.01*	1.24	0.01*	1.25	0.01*		
	3	1.22	0.00*	1.23	0.01*	1.24	0.01*	1.25	0.01*		
	average	1.23		1.23		1.24		1.24			
28 March	1	1.27	0.01*	1.27	0.01*	1.37	0.01*	1.35	0.01*	1.38	0.01
	2	1.26	0.01*	1.27	0.01*	1.33	0.01*	1.35	0.01*	1.30	0.01*
	3	1.28	0.01*	1.26	0.01*	1.34	0.01*	1.31	0.01	1.32	0.01*
	average	1.27		1.27		1.35		1.35		1.31	

* Indicates that parameter value has been used in calculating the average.

Table 2 Temporal and spatial changes in fractal dimension D_2.

Date	Replicate	Cedar Creek: upstream		downstream		Strawberry Creek: upstream		downstream		plume	
7 March	1	1.74	0.01*	1.73	0.01*	1.75	0.01*	1.76	0.01*		
	2	1.73	0.01*	1.70	0.01*	1.74	0.01*	1.76	0.01*		
	3	1.75	0.01*	1.73	0.01*	1.79	0.01	1.75	0.01*		
	average	1.74		1.72		1.74		1.76			
28 March	1	1.74	0.01*	1.70	0.01*	1.68	0.01*	1.78	0.01*	1.74	0.01*
	2	1.72	0.01*	1.70	0.01*	1.64	0.02*	1.74	0.01*	1.74	0.01*
	3	1.71	0.01*	1.67	0.01*	1.69	0.01*	1.79	0.01*	1.73	0.01*
	average	1.73		1.69		1.67		1.77		1.74	

* Indicates that parameter value has been used in calculating the average.

where b_1 and b_2 are the regression coefficients and S_{b_1} and S_{b_2} are the standard errors of the regression coefficients. Using $H_0 : b_1 = b_2$ and $H_1 : b_1 \neq b_2$, the shading in Tables 3 and 4 indicates for which sample pairs H_0 could not be rejected at a significance level α of 0.01 (two-tailed), corresponding to a critical value of t of 2.576. In addition, for all samples the 95% confidence interval of the regression coefficient was calculated and for each possible sample pair the overlap of the confidence intervals was checked. With few exceptions, sample pairs for which H_0 could not be rejected had overlapping confidence intervals. It is evident from Tables 3 and 4 that sampling in triplicate is essential for determining fractal dimensions since in several instances only two replicates provided similar values. To simplify the following discussion, Tables 1 and 2 also show fractal dimensions for each sampling site calculated as the average of all three or just two replicates, depending on the number of replicates with similar fractal dimensions.

A comparison of the 7 March 1997 data shows that all sites, upstream and downstream along both Cedar Creek and Strawberry Creek, had similar values of D (i.e. H_0 is not rejected) (Table 1). The values of D_2 were similar at all sites also (Table 2). The explanation for the similarity between the basins and between the sites within each basin is that on this day there was no surface runoff contributing water and sediment to either stream. As a result, the only active sediment sources were located in the channel and sediment concentrations were very low (4 mg l^{-1} or less). In contrast, on 28 March 1997 sampling took place during a runoff event resulting from the melt of a freshly fallen snowpack which had accumulated after the main snowpack of the winter had melted earlier. Under these conditions the main suspended sediment sources were the channel system, farmland because of overland flow and, possibly, tile drains. At all sites, D increased relative to the previous sampling date (Table 1). The increase, however, was greater in Strawberry Creek (from $D = 1.24$ on 7 March to $D = 1.35$ on 28 March at both sites) than in Cedar Creek (from $D = 1.23$ on 7 March to $D = 1.27$ on 28 March at both sites). At the Cedar Creek sites, D_2 showed little change from 7 March to 28 March (Tables 2 and 4). In the Cedar Creek basin the presence of a wider buffer zone prevented the sediment-laden overland flow generated on farmland from reaching the stream and as a result there would be no reason to expect an influx of particles between the upstream and downstream sites. This hypothesis is supported by the low sediment concentrations (4 mg l^{-1} or less) at both sites. In the Strawberry Creek basin, with much narrower buffer zones, it was observed that overland flow from farmland crossed the buffer zone, resulting in distinct plumes of sediment-laden water and an increase in sediment concentration from 13 mg l^{-1} at the upstream site to 131 mg l^{-1} at the downstream site. At both sites $D = 1.35$, despite the influx of overland flow between the two sites. One overland flow plume was sampled. For this plume $D = 1.31$ and Table 3 shows that this value is similar to some of the replicates at the upstream and downstream sites on Strawberry Creek on that day. At the Strawberry Creek upstream site, D^2 showed significantly lower values on 28 March than on 7 March. At the downstream site, however, there was little change in D^2.

The contrasting temporal changes in D and D^2 between the two basins can be explained by contrasting basin conditions. In the Cedar Creek basin the extensive riparian zones effectively limit the transport of sediment carried by surface runoff

Table 3 *t* statistic for *D*.

		Cedar down March 7			Cedar up March 7			Strawb down March 7			Strawb up March 7			Cedar down March 28			Cedar up March 28			Strawb down March 28			Strawb up March 28			Strawb plume March 28		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cedar down	1																											
March 7	2	-3.0681																										
	3	-2.5062	0.9188																									
Cedar up	1	-2.0620	1.4053	0.5436																								
March 7	2	-2.9135	0.8280	-0.1837	-0.7922																							
	3	-2.3010	1.3374	0.4294	-0.1483	0.6839																						
Strawb down	1	-3.9469	-0.1943	-1.3539	-1.9816	-1.3051	-1.9454																					
March 7	2	-5.7087	-1.7604	-3.1857	-3.8780	-3.3294	-3.9481	-1.9476																				
	3	-4.8479	-1.0913	-2.3621	-3.0025	-2.4107	-3.0179	-1.1099	0.7768																			
Strawb up	1	-2.2661	0.1677	-0.5466	-0.9180	-0.4505	-0.8460	0.3368	1.5628	1.0427																		
March 7	2	-2.6578	-0.3060	-1.0216	-1.3817	-0.9470	-1.3215	-0.1905	0.9784	0.4896	-0.4103																	
	3	-3.2404	-0.7565	-1.5398	-1.9252	-1.4847	-1.8754	-0.6831	0.5412	0.0349	-0.8044	-0.3705																
Cedar down	1	-5.8874	-2.9985	-4.0680	-4.5414	-4.1387	-4.5598	-3.1997	-1.8444	-2.3675	-2.7165	-2.1920	-1.8594															
March 28	2	-5.8434	-3.0210	-4.0628	-4.5232	-4.1268	-4.5379	-3.2124	-1.8892	-2.4003	-2.7468	-2.2293	-1.9016	-0.0721														
	3	-5.2113	-2.4560	-3.4374	-3.8820	-3.4704	-3.8798	-2.5781	-1.2698	-1.7843	-2.2646	-1.7662	-1.4255	0.4230	0.4873													
Cedar up	1	-7.1044	-3.6105	-4.9998	-5.6034	-5.1958	-5.6931	-4.0255	-2.4060	-3.0084	-3.1353	-2.5365	-2.1921	-0.1639	-0.0808	-0.6277												
March 28	2	-5.5528	-2.3296	-3.4990	-4.0357	-3.5757	-4.0590	-2.5057	-0.9639	-1.5686	-2.0985	-1.5549	-1.1796	0.8794	0.9414	0.3999	1.1814											
	3	-7.5852	-4.0366	-5.4845	-6.1031	-5.7163	-6.2124	-4.5266	-2.8992	-3.4939	-3.4835	-2.8695	-2.5376	-0.5341	-0.4437	-0.9887	-0.4238	-1.5939										
Strawb down	1	-14.0137	-10.5056	-12.2904	-12.9276	-12.7741	-13.1705	-11.6409	-10.2317	-10.6467	-9.1199	-8.3708	-8.2368	-6.7832	-6.6036	-7.0608	-7.3888	-8.2521	-7.0278									
March 28	2	-14.5440	-10.7484	-12.7320	-13.4374	-13.3188	-13.7378	-12.0758	-10.5663	-10.9935	-9.2027	-8.4130	-8.2855	-6.7962	-6.6044	-7.0783	-7.4737	-8.3682	-7.0944	0.2735								
	3	-10.4343	-7.0180	-8.5808	-9.1849	-8.9202	-9.3502	-7.8026	-6.3372	-6.8235	-6.0797	-5.4118	-5.1806	-3.4836	-3.3500	-3.8416	-3.7400	-4.7276	-3.3582	3.5477	3.4258							
Strawb up	1	-12.3051	-9.6227	-10.8681	-11.3248	-11.1104	-11.4359	-10.2703	-9.1536	-9.5190	-8.7110	-8.0998	-7.9468	-6.6251	-6.4854	-6.8847	-7.0159	-7.7702	-6.7143	-0.8158	-1.0720	-3.8441						
March 28	2	-8.1295	-6.0983	-6.8973	-7.2210	-6.9610	-7.2375	-6.3293	-5.4210	-5.7570	-5.7198	-5.2708	-5.0626	-3.7770	-3.6903	-4.0483	-3.8779	-4.5715	-3.6203	1.2317	1.0617	-1.3177	1.7665					
	3	-10.7990	-8.1391	-9.3230	-9.7712	-9.5261	-9.8611	-8.6891	-7.5552	-7.9404	-7.3653	-6.7801	-6.5944	-5.1920	-5.0664	-5.4774	-5.4799	-6.2718	-5.1716	0.7072	0.4945	-2.3292	1.3591	-0.5825				
Strawb plume	1	-17.3614	-13.4607	-15.6336	-16.3715	-16.3377	-16.7349	-15.0706	-13.5900	-13.9666	-11.5574	-10.7000	-10.6469	-9.3353	-9.1071	-9.5577	-10.2839	-11.0903	-9.9176	-2.4090	-2.7966	-6.1310	-1.2195	-3.0022	-2.7993			
March 28	2	-7.8600	-5.2759	-6.3143	-6.7383	-6.4277	-6.7798	-5.6074	-4.4488	-4.8732	-4.7987	-4.2707	-4.0188	-2.4587	-2.3632	-2.7957	-2.5286	-3.3934	-2.2088	3.5852	3.4630	0.5531	3.9047	1.6267	2.5521	5.7792		
	3	-10.5512	-7.4880	-8.8724	-9.4013	-9.1423	-9.5276	-8.1598	-6.8510	-7.2900	-6.6199	-5.9864	-5.7764	-4.2125	-4.0812	-4.5369	-4.4917	-5.3889	-4.1435	2.3178	2.1463	-1.0090	2.7963	0.5327	1.3458	4.6777	-1.3977	

Table 4 *t* statistics for D_2.

		Cedar down March 7			Cedar up March 7			Strawb down March 7			Strawb up March 7			Cedar down March 28			Cedar up March 28			Strawb down March 28			Strawb up March 28			Strawb plume March 28		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Cedar down	1																											
March 7	2	1.8299																										
	3	-0.1231	-1.9186																									
Cedar up	1	-0.5153	-2.3730	-0.3759																								
March 7	2	-0.2588	-2.2395	-0.1147	0.3166																							
	3	-1.5152	-3.3009	-1.3505	-1.0586	-1.4919																						
Strawb down	1	-2.8107	-4.4086	-2.6245	-2.4688	-3.0201	-1.5158																					
March 7	2	-2.7199	-4.3350	-2.5340	-2.3693	-2.9174	-1.4036	0.1220																				
	3	-1.4749	-3.2444	-1.3143	-1.0223	-1.4389	0.0136	1.4915	1.3817																			
Strawb up	1	-1.1795	-2.6152	-1.0693	-0.8254	-1.0791	-0.1037	0.9018	0.8233	-0.1116																		
March 7	2	-0.7557	-2.2179	-0.6501	-0.3860	-0.6209	0.3442	1.3409	1.2643	0.3313	0.3584																	
	3	-4.3137	-5.5172	-4.1700	-4.0903	-4.4873	-3.4547	-2.4047	-2.4966	-3.4227	-2.6468	-2.9995																
Cedar down	1	2.2748	0.4580	2.3568	2.8175	2.7050	3.7234	4.7886	4.7185	3.6650	2.9809	2.5909	5.8213															
March 28	2	1.9967	0.2740	2.0790	2.4979	2.3722	3.3448	4.3609	4.2920	3.2959	2.7343	2.3576	5.4785	-0.1641														
	3	3.8203	2.0061	3.8841	4.3763	4.3227	5.2461	6.2185	6.1573	5.1794	4.2956	3.9209	7.0011	1.5412	1.6505													
Cedar up	1	-1.0315	-2.6994	-0.8988	-0.6006	-0.9146	0.3030	1.5526	1.4588	0.2865	0.3155	-0.0939	3.3545	-3.1086	-2.8059	-4.5669												
March 28	2	0.5052	-1.2663	0.6132	1.0060	0.7975	1.9328	3.1090	3.0265	1.8919	1.5365	1.1322	4.5122	-1.7052	-1.4678	-3.2197	1.4493											
	3	1.5285	-0.3756	1.6252	2.1000	1.9498	3.0961	4.2897	4.2113	3.0347	2.3860	1.9721	5.4185	-0.8453	-0.6373	-2.4328	2.4568	0.9464										
Strawb down	1	-3.4988	-4.8568	-3.3433	-3.2273	-3.6602	-2.4873	-1.2963	-1.3973	-2.4596	-1.7743	-2.1587	1.1100	-5.1937	-4.8285	-6.4776	-2.4456	-3.7428	-4.7389									
March 28	2	-1.1078	-2.7570	-0.9753	-0.6852	-1.0004	0.2053	1.4425	1.3490	0.1906	0.2443	-0.1623	3.2635	-3.1624	-2.8602	-4.6102	-0.0825	-1.5178	-2.5186	2.3490								
	3	-4.6345	-5.8772	-4.4656	-4.4268	-4.9226	-3.7385	-2.5425	-2.6487	-3.6916	-2.7146	-3.0935	0.1453	-6.1854	-5.7840	-7.4048	-3.5501	-4.8053	-5.8159	-1.0606	-3.4456							
Strawb up	1	3.2036	1.5102	3.2712	3.7049	3.6236	4.5090	5.4389	5.3776	4.4554	3.7623	3.4021	6.3675	1.0729	1.1932	-0.3951	3.9357	2.6611	1.8975	5.7989	3.9816	6.6919						
March 28	2	5.0850	3.4890	5.1353	5.5623	5.5252	6.2846	7.0869	7.0356	6.2300	5.4343	5.1042	7.7994	3.0673	3.1335	1.6639	5.7087	4.5516	3.8881	7.3339	5.7443	8.1268	1.9728					
	3	2.4943	0.8363	2.5683	2.9751	2.8687	3.7692	4.7122	4.6483	3.7221	3.1468	2.7865	5.7621	0.4092	0.5490	-1.0373	3.2473	1.9783	1.2005	5.1474	3.2969	6.0490	-0.6203	-2.5480				
Strawb plume	1	-0.8538	-2.4941	-0.7286	-0.4281	-0.7166	0.4432	1.6360	1.5465	0.4254	0.4223	0.0225	3.3841	-2.8999	-2.6162	-4.3417	0.1353	-1.2723	-2.2429	2.4970	0.2139	3.5663	-3.7376	-5.5108	-3.0624			
March 28	2	-0.6987	-2.1415	-0.5958	-0.3341	-0.5613	0.3811	1.3551	1.2802	0.3682	0.3892	0.0360	2.9900	-2.5109	-2.2847	-3.8276	0.1331	-1.0719	-1.8954	2.1597	0.2000	3.0778	-3.3205	-5.0150	-2.7124	0.0179		
		-0.3350	-1.9339	-0.2245	0.0869	-0.1515	0.9062	1.9988	1.9176	0.8841	0.7880	0.4058	3.6063	-2.3356	-2.0908	-3.7510	0.5740	-0.7611	-1.6624	2.7753	0.6447	3.7795	-3.2018	-4.9843	-2.5510	0.4348	0.3610	

into the stream. As a result, even during snowmelt conditions the sediment concentrations remain low and both D and D^2 show little change. The slight increase in D (from 1.23 to 1.27) likely reflects the input of fines and organic matter by surface runoff. This interpretation is consistent with the slight decrease in D^2 at both sites, as the added fines and organic matter would result in more complex shapes of the larger particles. In the Strawberry Creek basin the marked increase in D likely reflects a similar input of fines and organic matter during the snowmelt. The low effectiveness of the buffer strips results in a larger input of sediment than in the Cedar Creek basin. This results in much higher sediment concentrations for Strawberry Creek and in the large increase in D. Furthermore, on 28 March D^2 is low at the upstream site of Strawberry Creek, reflecting the intricate shapes associated with predominantly in-channel sources. The increase in D^2 at the downstream site is explained by the input of sediment with more regular shapes, which is consistent with the value of D^2 for the plume.

CONCLUSIONS

Suspended solids were collected at upstream and downstream locations in two first order basins. The two basins differ in drainage area, land use, Quaternary geology as well as in the extent and type of riparian vegetation. Differences in fractal dimensions between upstream and downstream sites, between Strawberry Creek and Cedar Creek and through time can be explained by differences in land use and by temporal changes in the contributions of the various sediment sources within the basins.

Assuming that $D^2 = D^3$ (Kilps *et al.*, 1994), equations presented by Logan & Kilps (1995) can be used to predict how the properties of the flocs scale with floc size l. For example, floc density scales with l^{D_2-3}. Hence, if $D^2 = 1.67$, an increase in floc size by a factor of 10 would result in a decrease in density by a factor of 21.4. Conversely, if $D^2 = 1.77$ a similar increase in floc size would cause a decrease in density by a factor of 17. Thus, D^2 can be used to predict changes in floc density which can be used for modelling the fate of the suspended solids. A similar approach can be applied to settling velocity. Overall, incorporating information on the fractal dimensions of suspended solids will allow the description of floc properties to improve over that used in current models, which should lead to a better understanding and prediction of the fate of suspended solids in flowing water.

Acknowledgements This project was funded by grants from the Natural Sciences and Engineering Research Council of Canada to Mike Stone and Dirk de Boer.

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