

A new definition of suspended sediment: Implications for the measurement and prediction of sediment transport

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Extended Abstract

While it is now well documented that cohesive suspended sediment is commonly transported in a flocculated/aggregated form (Figure 1) (Bale and Morris, 1987; Walling and Moorehead, 1989; Droppo and Ongley, 1994; Phillips and Walling, 1999; Droppo *et al.*, 2000; Droppo, 2001), research into sediment transport issues, still relies on traditional sedimentological

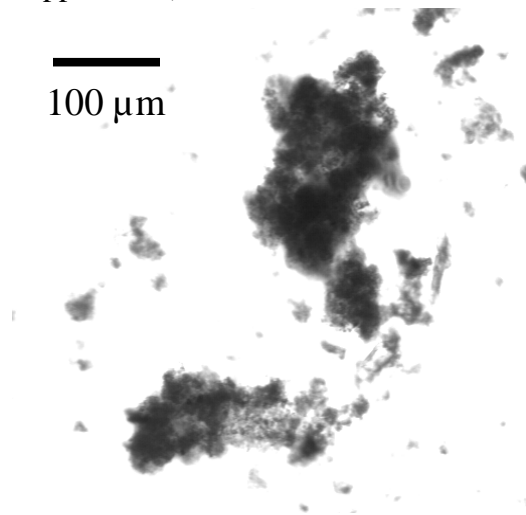


Figure 1. Example of typical fluvial flocs.

techniques. That is, the chemically dispersed mineral fraction (absolute particle size) is measured to characterize particle size and for input values to models for the prediction of sediment and contaminant source, fate and effect. This implicit or explicit assumption of single grain particles is motivated by a lack of a standard defining equation, which can explain the formation and interaction of flocs/aggregates with their surrounding aquatic environment, and the lack of a standard method for sampling, observing, and measuring such particles. Regardless, most rivers possess significant proportions of cohesive (fine-grained) sediments, and as such, for the reasons stated below, a knowledge of the particle structure is imperative for sediment/contaminant transport related studies.

Flocs/aggregates are heterogeneous, composite structures composed of an active biological component, a non-viable biological component, inorganic particles, and water held within or flowing through pores (Walling and Woodward, 1993; Droppo and Ongley, 1994; Liss *et al.*, 1996; Droppo *et al.*, 1998, 2000). Flocs are formed within the water column or on the surface of the bed by a variety of complicated physical, chemical and biological means. Alternatively, aggregates are generally considered to form outside of, and be transported to, the aquatic system as water stable soil aggregates. Aggregates transported in a water column will possess many of the same physical, chemical and biological characteristics as flocs (although denser with a concomitant higher settling velocity), and are generally optically indistinguishable from flocs (particularly when the two flocculate together). As such, for the purposes of this work, the terms floc/flocculation and aggregate/aggregation will be used interchangeably. The most significant impact of flocculation in terms of sediment and contaminant transport is that it alters the downward flux of sediment by changing the hydrodynamic properties of the sediment. This is brought about by flocculation increasing the effective particle size by orders of magnitude over

the absolute particle sizes and, as such, also changes the effective particle shape, density, porosity and composition of the characteristic particle (suspended or bed sediment) within a system (Li and Ganczarczyk, 1987; Nicholas and Walling, 1996; Droppo *et al.*, 2000; Phillips and Walling, 1999). A typical relationship of floc size to settling velocity, porosity and density is provided in Figure 2.

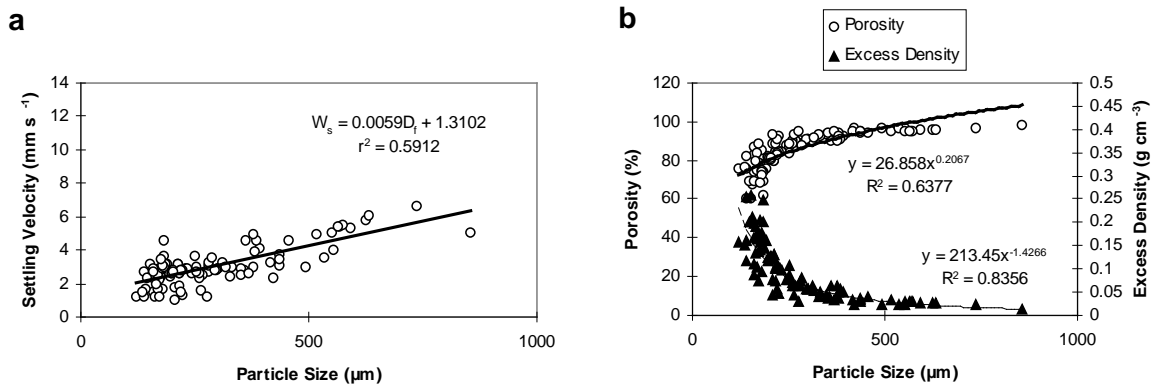


Figure 2. Examples of the typical relationship of floc size to a) settling velocity (note the increasing settling velocity with particle size) and b) density and porosity (note the increasing porosity and decreasing density with particle size).

A flocculated/aggregated particle is in continuous interaction with its aquatic surroundings, as the medium in which it is transported provides the floc with further building materials, energy, nutrients and chemicals for biological growth, chemical reactions and morphological development. While flocs can regulate their own characteristics, they are also known to be able to contribute to the regulation of their surrounding water quality through their physical, chemical and biological activity (Liss *et al.*, 1996). Given the complex composition of flocs and the complicated physical, chemical and biological interactions within flocs and within the systems where they occur, a new definition of suspended sediment particles (flocs) is required. Given the importance of the biological system within the particles, a floc definition is suggested as follows:

A floc is an individual microecosystem represented as a composite particle composed of a complex matrix of water, inorganic and organic particles, with autonomous and interactive physical, chemical and biological functions or behaviours operating within the floc matrix (modified from Droppo *et al.*, 1997; Droppo 2001).

While there are many studies of flocculation (e.g. Hunt, 1982; Kranck, 1984; Bale and Morris, 1987; Walling and Moorehead, 1989; Fennessy *et al.*, 1994; Droppo *et al.*, 1998, 2000) which focus on many different aspects of flocculation from a variety of different environments, very few papers have attempted to link the physical, chemical and biological aspects of flocculation together in a simple manner to enhance our understanding and learning of such an important phenomenon in our aquatic ecosystems. Furthermore, few papers have attempted to explain the impact that particle structure will have on our traditional measurement of sediment transport. This paper provides a comprehensive conceptual model with supporting documentation for the

explanation of the linkage between floc structure and floc behaviour (transport) within aquatic environments. Given the realization that the majority of cohesive sediment is not transported as single particle but rather as flocs or “microecosystems”, it is important that we gain a better understanding of what constitutes cohesive suspended sediment and its transport within aquatic ecosystems.

References

- Bale A.J. and Morris A.W. (1987) *In situ* measurement of particle size in estuarine waters. *Estuar. Coast. Shelf Sci.*, **24**, pp. 253-263.
- Droppo, I.G. (2001) Rethinking what constitutes suspended sediment. *Hydrol. Proc.*, **15**, pp. 1551-1564.
- Droppo I.G. and Ongley E.D. (1994) Flocculation of suspended sediment in rivers of Southeastern Canada. *Wat. Res.*, **28**, pp. 1799-1809.
- Droppo, I.G., Leppard, G.G., Flannigan, D.T., and Liss, S.N. (1997) The freshwater floc: A functional relationship of water and organic and inorganic floc constituents affecting suspended sediment properties. *Wat. Air Soil Pollut.*, **99**: 43-53.
- Droppo, I.G., Walling, D.E. and Ongley, E.D. (1998) Suspended Sediment Structure: Implications for sediment and contaminant transport modelling. In: *Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes*, Editors, W. Summer, E. Klaghofer and W. Zhang. July 13-17, 1998, Vienna, Austria., **IAHS Pub. no. 249**. pp. 437-444.
- Droppo, I.G., Walling, D.E. and Ongley, E.D. (2000) The influence of floc size, density and porosity on sediment and contaminant transport. In: *Role of Erosion and Sediment Transport in Nutrient and Contaminant Transfer*, Editor, M. Stone, July 10-14, 2000, Waterloo, Ontario, Canada. **IAHS Pub. no. 263**. pp. 141-147.
- Fennessy M.J., Dyer K.R. and Huntley D.A. (1994) INSSEV: An instrument to measure the size and settling velocity of flocs *in situ*. *Mar. Geol.*, **117**, pp. 107-117.
- Hunt J.R. (1982) Self-similar particle-size distributions during coagulation: Theory and experimental verification. *J. Fluid Mech.*, **122**, pp. 169-185.
- Kranck K. (1984) The role of flocculation in the filtering of particulate matter in estuaries. In: V.S. Kennedy (Ed.), *The Estuary as a Filter*. Academic Press, Orlando, Fla., pp. 159-175.
- Li D.-H. and Ganczarczyk J. (1987) Stroboscopic determination of settling velocity, size and porosity of activated sludge flocs. *Wat. Res.*, **21**, pp. 257-262.
- Liss S.N., Droppo I.G., Flannigan D. and Leppard G.G. (1996) Floc architecture in wastewater and natural riverine systems. *Environ. Sci. Technol.*, **30**, pp. 680-686.
- Nicholas A.P. and Walling D.E. (1996) The significance of particle aggregation in the overbank deposition of suspended sediment on river floodplains. *J. Hydrology*, **186**, pp. 275-293.
- Phillips J.M. and Walling D.E. (1999) The particle size characteristics of fine-grained channel deposits in the River Exe Basin, Devon, UK. *Hydrol. Proc.*, **13**, pp. 1-19.
- Walling D.E. and Moorehead P.W. (1989) The particle size characteristics of fluvial suspended sediment: An overview. *Hydrobiologia*, **176/177**, pp. 125-149.
- Walling D.E. and Woodward J.C. (1993) Use of a field-based water elutriation system for monitoring the *in situ* particle size characteristics of fluvial suspended sediment. *Wat. Res.*, **27**, pp. 1413-1421.