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Floc Size and Settling Velocity Observations From Three Contrastingly Different Natural Environments in the USA

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Environmentally, monitoring the movement of suspended cohesive sediments is highly desirable in both estuaries and lakes. When modelling cohesive sediment transport and mass settling fluxes, the settling speed of the suspended matter is a key parameter. In contrast to purely non-cohesive sandy sediments, mud can flocculate and this poses a serious complication to the modelling of sediment pathways. As flocs grow in size they become more porous and significantly less dense, but their settling speeds continue to rise due to a Stokes' Law relationship.

Much research has been conducted on the flocculation characteristics of suspended muddy sediments in saline/brackish tidal conditions, where electrostatic particle bonding can occur. However very little is known about freshwater floc dynamics. This is primarily due to flocs being extremely delicate entities and are thus very difficult to observe in situ. This paper primarily describes a recently developed, portable, low intrusive instrument INSSEV_LF, which permits the direct, *in situ* measurement of both floc size (D) and settling velocity (Ws), simultaneously.

Examples of floc spectra observed from three different environments within the USA are presented and compared. The first site was the turbidity maximum zone in San Francisco Bay, where the suspended solids concentration (SSC) was 170 mg.l^{-1} and many low density macroflocs up to 400 μm in diameter, settling at speeds of 4-8 mm.s^{-1} were observed.

The second location was the shallow (1.7 m mean depth), freshwater environment of Lake Apopka in Florida. It is highly eutrophic, and demonstrates a turbid SSC of 750 mg.l^{-1} within a benthic suspension layer. These conditions resulted in D from 45 μm up to 1,875 μm; 80% of the floc were $>$ 160 μm (i.e. macroflocs). Present theories for the settling of flocs rely on fractal theory of self-similarity, but this does not appear to be applicable to the Lake Apopka flocs because they do not possess any basic geometric unit that is the building block of higher order fractal structures. Bioflocculation is deemed extremely important in freshwater environments such as lakes. The Lake Apopka macroflocs (D $>$ 160 μm) encompassed 92% of the floc mass, and demonstrating a Ws$_{macro}$ of 1.7 mm.s^{-1} (twice as fast as the Ws$_{micro}$), this translated into the macroflocs contributing 96.4% of the total mass settling flux (1.5 g.m^{-2}s^{-1}).

Lake Tahoe, which crosses California and Nevada, was the final study location. With a maximum depth of 501 m, it is the second deepest freshwater lake in the USA. However it significantly less turbid than Lake Apopka, with SSC rarely exceeding 10 mg.l^{-1} during the floc surveys. At depths of both 5 m and 450 m, the SSC was 9.6 and 3 mg.l^{-1}, respectively. Flocs at both depths exhibited Ws of 2-5 mm.s^{-1}. Whereas at a depth of 35 m (Fig. 3c), the SCC was 6.8 mg.l^{-1} and the flocs fell comparatively slowly (Ws of 0.03-2.4 mm s^{-1}) which suggest that the floc population at 35 m will have a long residence time in the water column, thus impairing long term light penetration. Interestingly, the MSF at 450 m was 10.8 mg.m^{-2}s^{-1}, which was double the flux measured at 35 m, even though the deep water was only half as turbid.

This comparison indicates that the size and settling velocity of individual flocs can be measured simultaneously

with the video INSSEV_LF instrument within SSC of several g.l^{-1}. This floc data is of great importance for accurate numerical sediment transport model calibration in estuaries (e.g. San Francisco Bay), whilst also equally valuable for addressing environmental problems (e.g. water quality issues) in freshwater environments such as Lake Tahoe and Lake Apopka.