Floc Modeling: Mechanisms of Flocculation and Clarification

Anjali Asthagiri, Isabel Crovella, Alex Gardocki, Lauren Hsu, Max Zheng, Monroe Weber-Shirk
AguaClara Cornell, Civil and Environmental Engineering, Cornell University

Abstract

An accurate mechanistic model of flocculation and clarification is essential for optimizing the design and operation of AguaClara water treatment plants, ultimately enhancing treatment efficiency and accessibility. This study integrates theory, experimentation, and computational modeling to develop a mathematical framework that captures key mechanisms, including floc filter dynamics, interactions between coagulant and clay particles, and coagulant adhesion to flocculator walls. Experiments were conducted to investigate and validate these mechanisms.

Introduction

Flocculation & Clarification Processes

- **Flocculation** combines primary particles into larger aggregates called flocs.
- **Clarification** allows the newly formed flocs to settle and separate from the treated water. AguaClara plants utilize a process called **floc sweeping**, where previously formed flocs capture additional primary particles in a suspension called a **floc filter**.
- Floc sweeping efficiency depends on **floc saturation**. As a floc captures primary particles, its pores fill. A fully saturated floc cannot capture additional particles.

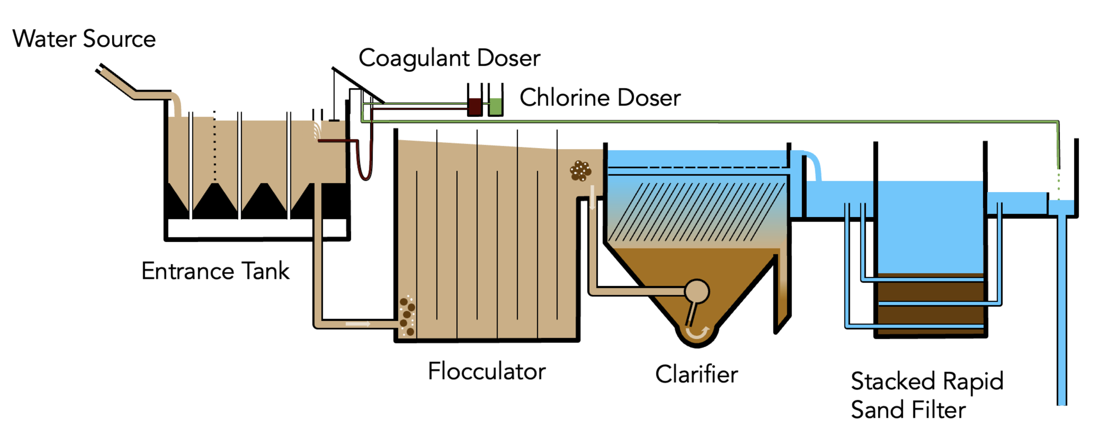

Figure 1. Design of an AguaClara drinking water treatment plant.

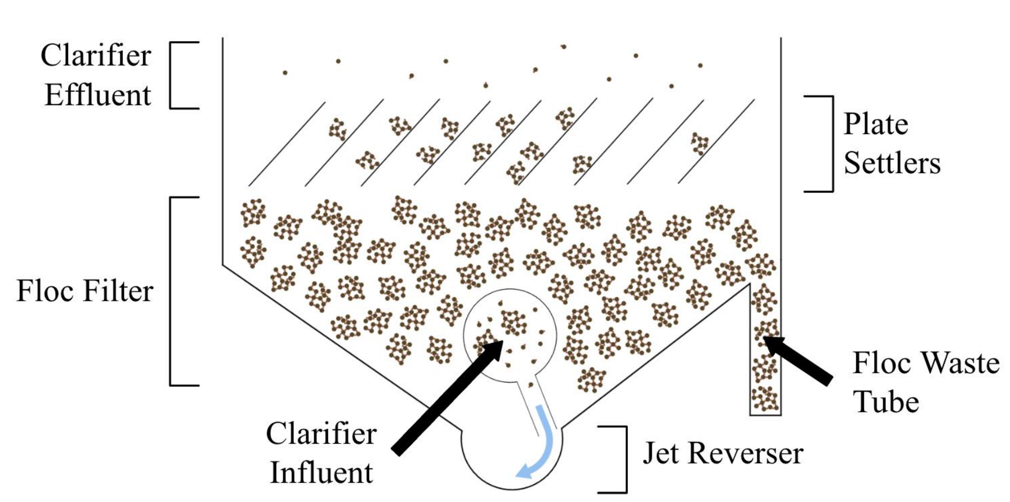

Figure 2. AguaClara clarifier schematic (left).

Applications of a Mathematical Model

Automated Coagulant Dosing Controller (ACDC)
- Reduce operational costs by removing the need for a full-time plant operator and optimizing coagulant use

Clarifier & Flocculator Design
- Improve particle removal efficiency in the floc filter through strategic placement of the waste tube
- Optimize floc formation and particle removal

Fundamental Understanding
- Enhance future discovery and innovation in surface water treatment technologies

Mathematical Modeling

Flocculation & Rapid Mix Model

The following mechanisms are considered in the model:
- Particle collisions driven by diffusion and shear
- PACl attachment to the walls of the tube flocculator
- Formation of aggregates from PACl-PACl and PACl-PP collisions
- Collision energy limit due to finite bond strength

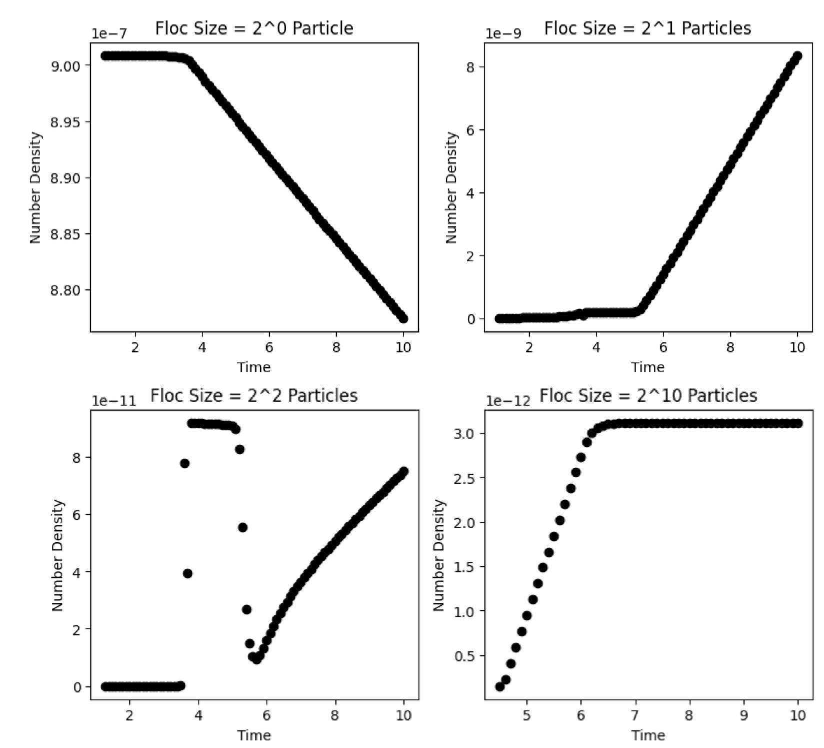

Figure 3. Model predictions for the rate of particle-particle aggregation.

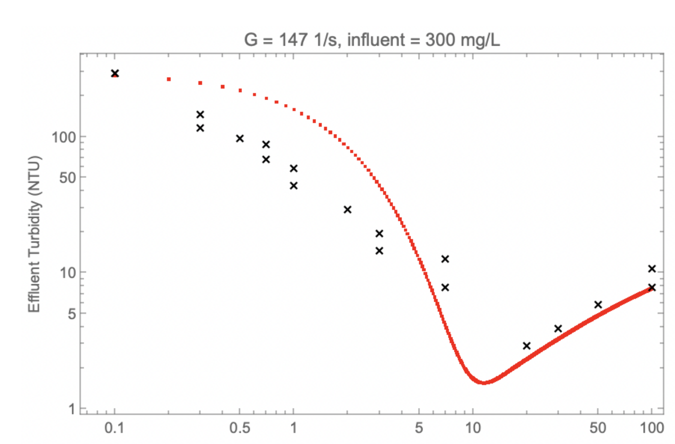

Figure 4. Model predicts flocculation failure at high coagulant doses (overdosing). Data adapted from Pennock et al., 2018.

Clarification Model

Floc sweeping in the floc filter results in the saturation of flocs (Fig. 5). This process competes with the addition of new (unsaturated) flocs from the flocculator. The following model couples these mechanisms with the AguaClara Flocculation Model. Reasonable theoretical values of system parameters results in an appropriate fit at high turbidities (Fig. 6). Further research is necessary to improve model predictions at low turbidities.

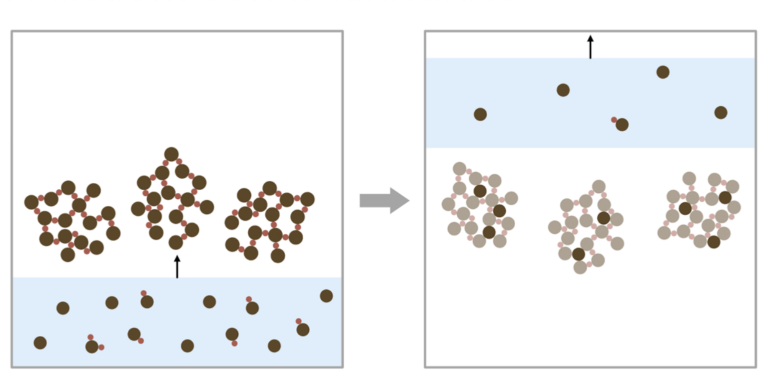

Figure 5. Floc sweeping process resulting in floc saturation.

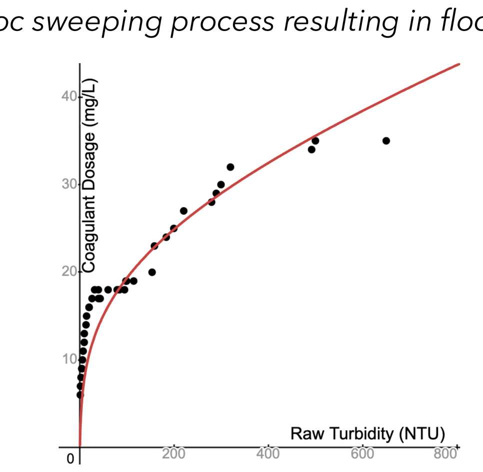

Figure 6. Theoretical clarification model fits reasonably to operator data from AguaClara plants in Nicaragua.

Theory

A proposed mechanistic framework is outlined in Figure 7, developed based on literature, experimentation, and model findings.

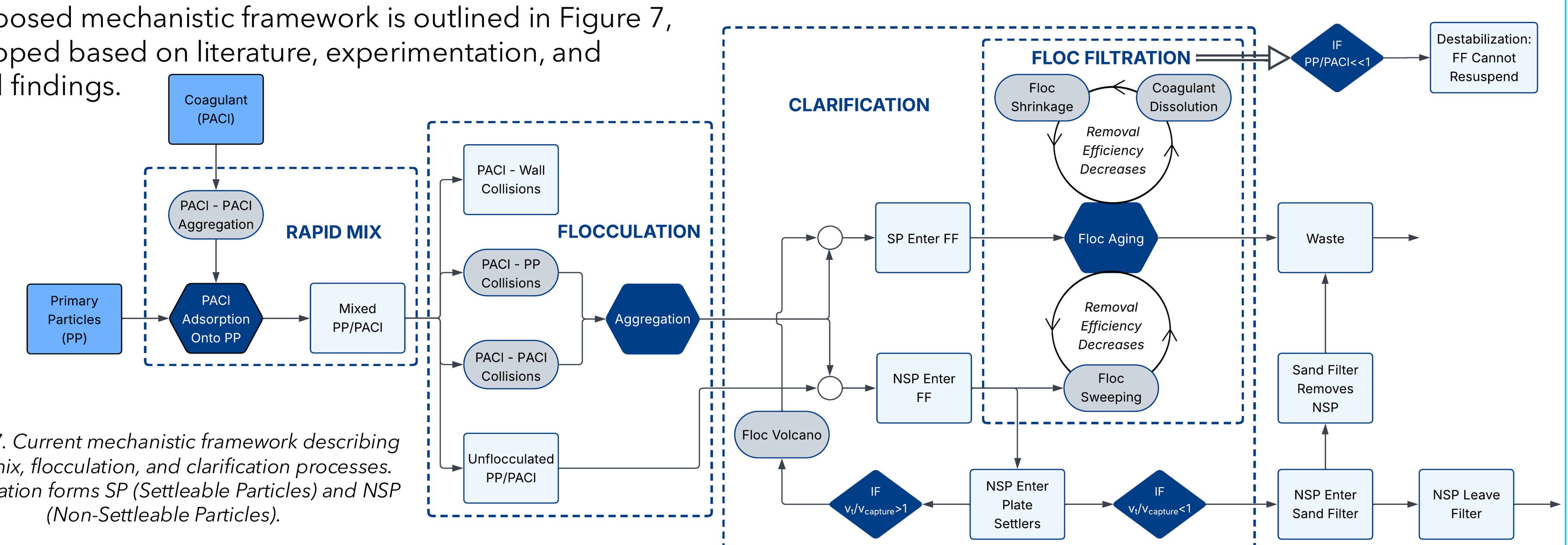

Figure 7. Current mechanistic framework describing rapid mix, flocculation, and clarification processes. Aggregation forms SP (Settleable Particles) and NSP (Non-Settleable Particles).

Experimentation

A novel experimental approach is developed to investigate flocculation and clarification dynamics.

Experimental Setup

A bench-scale clarifier (25 cm height) was developed for real-time imaging of the floc filter. By introducing colored primary particles before clarification, gradients in relative coloration can indicate floc filter saturation.

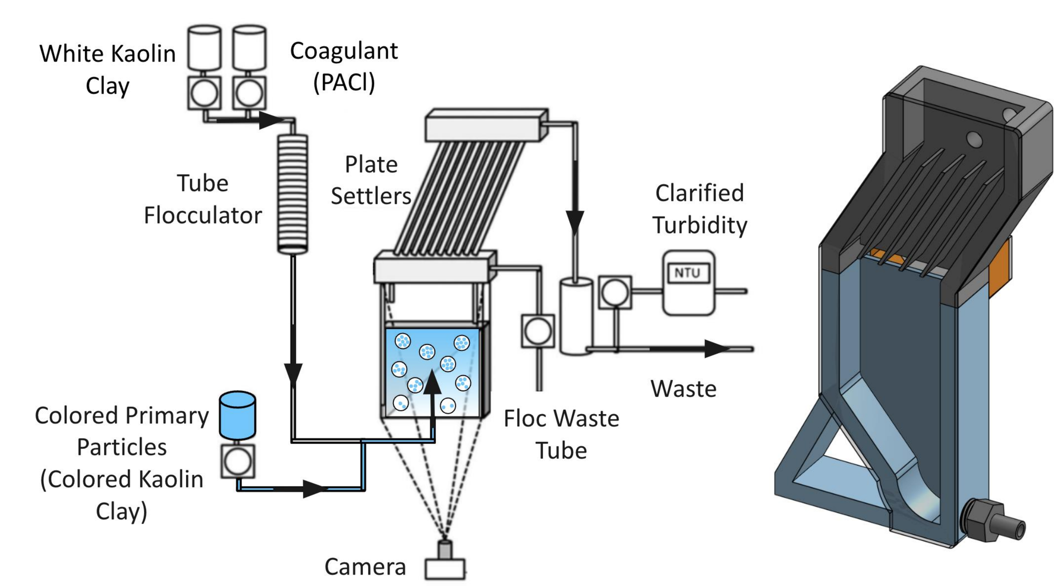

Figure 8. Experimental apparatus (left) and bench-scale clarifier (right).

Observations

- Flocs become colored, indicating the capture of colored primary particles (Fig. 9, middle)
- Flocs densify over time, becoming smaller and harder to suspend (Fig. 9, middle)
- Size and density of initially-formed flocs depend on influent turbidity and coagulant dose
- High coagulant doses result in an unstable floc filter, unable to remain suspended (Fig. 9, right)

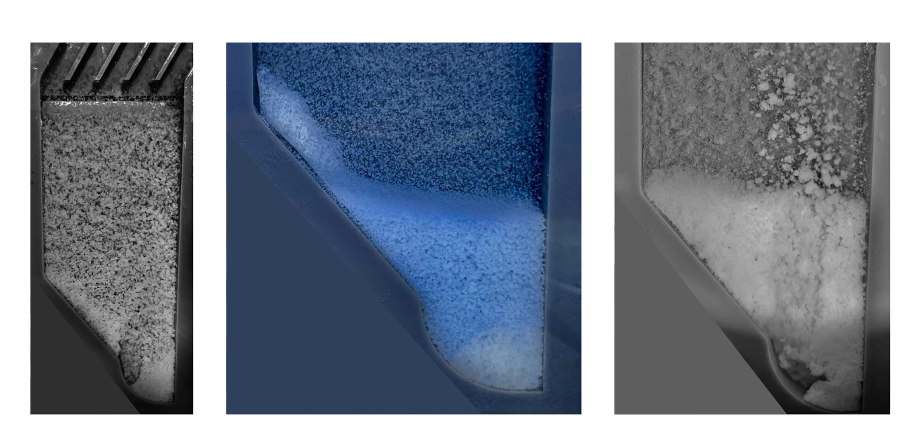

Figure 9. Bench-scale clarifier, images from experiments.

Future Work

- Continue developing the flocculation model, considering coagulant bonding mechanisms and fractal geometry
- Develop flocculator apparatus that enables visualization of flocculator dynamics
- Collect quantitative data via flow meters, cameras, and microscopes to validate the models

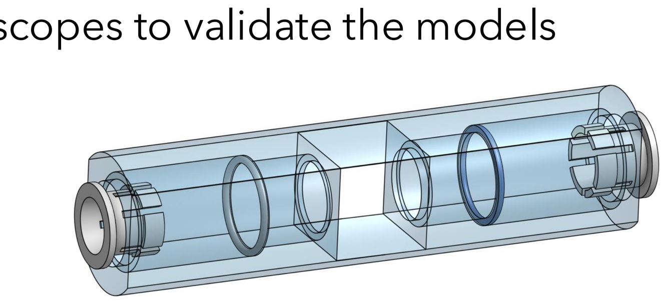

Figure 10. Flocculator inserts for floc visualization.

References

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Contact: Anjali Asthagiri – aa2549@cornell.edu