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Can there be a Law of Conservation of Turbidity

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Abstract

Water quality models are successful in tracking the movement of various constituents through a distribution system. With some exceptions, at most nodes in a model, complete mixing occurs and the concentration after mixing can be given by a standard materials balance equation.

This paper used benchtop batch mixing tests and a lab scale physical model of a water distribution system to test the hypothesis that standard water quality models based on a simple materials balance can be used to track turbidity through a water system. The results showed that as long as the components being mixed had similar concentration vs. Turbidity relationships, a materials balance was accurate but the accuracy decreased as the particle properties of the components differed.

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1. Introduction

In some situations, model users would like to estimate turbidity values using water quality models. The extent to which those results would be accurate is related to the extent to which the materials balance equation can be applied to turbidity. There are three overall processes governing solids motion in water distribution systems: Sedimentation, resuspension and transport. This paper focuses on the transport of solids and their effect on the turbidity of water.

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In practical modeling, it would be desirable to be able to use a materials balance equation for turbidity (and most likely some have). However, it would be desirable to have some justification for doing so and understand any limitations. It seems logical that turbidity would be conserved in a water distribution system. If turbidity could be modeled as a conservative substance, it would be easy to track in in an existing model such as EPANET or WaterGEMS/CAD. It is much easier to determine the turbidity of a sample than parameters such as suspended solids concentration which require more time consuming analytical techniques.

This paper presents some theory showing the basis for tracking transport of turbidity, then describes some bench-top and physical scale model experiments, and discusses the implications for water quality modeling.

Theory

The principal of conservation of mass states that for a mixture, the mass flow can be given by

$$C_3V_3 = C_1V_1 + C_2V_2 \quad (1)$$

Where C = concentration, mg/L, V = volume, L, 1 and 2 and inputs and 3 is the resulting mixture.

$$V_3 = V_1 + V_2 \quad (2)$$

For a flowing system, volume can be replaced by flow (Q).

The concentration can be related to the turbidity according to a generalized function

$$C = f(T) \quad (3)$$

Where T is turbidity

Substituting into equation (1) yields

$$f_3(T_3)V_3 = f_1(T_1)V_1 + f_2(T_2)V_2 \quad (4)$$

Solving for the turbidity of the mixture yields

$$T_3 = f_3^{-1}\left(\frac{f_1(T_1)V_1+f_2(T_2)V_2}{V_3}\right) \quad (5)$$

This equation can be viewed as a generalize Law of Conservation of Turbidity. It requires knowing the relationship between turbidity and the solid particles causing turbidity over the range of interest for the problem at hand.

There are some special cases where the equation can be applied. The simplest is the case where the relationship between turbidity and concentration of solids is linear, passes through the origin and is the same for the two inputs and the resulting mixture.

$$C = aT \quad (6)$$

In this case, equation (5) can be reduced to

$$T_3 = \left(\frac{T_1V_1+T_2V_2}{V_3}\right) \quad (7)$$

Which is essentially the same as equation (1).