

# The Characteristics of Particles Behavior in Wetland during Dry Days

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Abstract: Samples were collected from the 7.8 k·m<sup>2</sup> wetland in Gimje City, Korea and analyzed for their particle size distribution and particle removal efficiency on dry days. The monitoring and surveying was conducted from July 9, 2009 to September 5, 2009, with samples immediately analyzed using a particle analyzer. The results indicated that particles were finer in the outflow than the inflow due to sedimentation of the coarse particles and resuspension of the fine particles in the wetland on dry days, and that the particle size distribution was, to a certain extent, affected by the flow rate. Particles in different size ranges play different roles in their contribution to turbidity and total suspended solids (TSS). Generally, turbidity was mainly related to particles less than 10  $\mu$ m in size and TSS to particles coarser than 4  $\mu$ m, which accounted for only a small number fraction, which was in agreement with the volume fraction. The particles in the wetland indicated a seasonal characteristic, with particle concentrations showing a peak in summer. There was a turning point for the removal efficiency of particles less than 30  $\mu$ m, which lay within the range of 2~4  $\mu$ m, i.e. the colloids limit value. The removal efficiencies of turbidity, TSS and particles in the wetland were related to antecedent dry days (ADD). ADD also affected the particle size distribution and uniformity coefficients.

Keywords: Wetland; Surface water; Particle size distribution; Removal efficiency; ADD

#### 1. Introduction

Suspended particles play an important role in the ecology and water quality of aquatic ecosystems. They can serve as a transport vector and carriers of diverse contaminants in surface water due to their large surface to volume ratio, especially for particles finer than 2  $\mu$ m, and the specific surface area of fine particles (< 2  $\mu$ m diameter) typically ranges between 10 and 100 m<sup>2</sup> · g<sup>-1</sup>. The cation exchange capacity of suspended particles is also closely related to their particle size composition <sup>[1]</sup>.

Wetland systems have long hydraulic residence times, generally several days or longer. Consequently, virtually all settable and floatable solids of wastewater origin are removed. The major processes responsible for the removal of settable suspended solids are sedimentation and filtration. Non-settling or colloidal solids are removed mainly by bacterial growth and collisions with and the adsorption to other solids <sup>[2-3]</sup>. the removal of suspended particles is the basic mechanism for pollutants removal <sup>[4]</sup> and; in this respect, information on the characteristics of particles behavior in surface water is of fundamental importance in understanding and modeling the transport of sediment and sediment-associated contaminants, including heavy metals, nutrients, micro-organics and radionuclide <sup>[5]</sup>.

After the suspended material reaches the wetland, it

joins large amounts of internally generated suspended materials, and both are transported across the wetland. Traditionally, there is a strong particle size dependence with respect to particles sedimentation and transport in wetland <sup>[5]</sup>, where coarse particles (e.g., > 10  $\mu$ m diameter) settle rapidly because of their density <sup>[6]</sup> and the particles with diameters of 10  $\mu$ m will descend 1 meter (20°C) over several hours, without adsorption or other surrounding interruptions.

However, many physical mechanisms can occur in wetland surface water, such as sedimentation, resuspension and coagulation, etc (Figure 1). Resu- spension has a large contribution to the particles number, and the wetland environment provides an opportunity for several mechanisms of resuspension: hydrodynamic shear forces may tear particles loose from the sediment bed, which is a dominant mechanism; the effects of vegetation can also play an important role in determining the particles number; there are also some other mechanisms, such as winddriven turbulence, bioturbation and gas lift. These processes are affected by the fluid properties (temperature, viscosity and density), particle properties (size, density and concentration), wetland morphometry and hydraulic resistance from vegetation, and these effecting factors are uncertain and random in the wetland. Thus, the particles behavior in wetland is not always exactly in agreement





Figure 1. Schematic diagram of the particles behavior in the wetland.

with traditional settling theory, especially for fine particles, but is complicated and not clearly defined. For this reason, it is desirable to have specific information on the behavior of particles transported in wetland.

The amount of particles in water can be described using the total suspended solids (TSS) concentration and turbidity. The TSS are measured gravimetrically after filtration and drying, and reported in mg/L<sup>[3]</sup>. Turbidity is a measure of the degree to which water looses its transparency due to the presence of suspended particulates; the measurement technique involves light scattering, and the standard unit is the nephelometric turbidity unit (NTU). The more total suspended solids in water, the murkier it appears and the higher the turbidity. The correlation between TSS and turbidity is often good for a specific wetland system. However, due to the different measurement techniques, the TSS and turbidity may be determined by particles within different size ranges in wetland surface water. In the treatment of agricultural runoff using a wetland, the removal of suspended solids is necessary and important, because these particles contain a lot of pollutants, including heavy metals, organic matters and nutrients; thus, it is essential to have a clear idea of the role of particles in contributing to TSS and turbidity, which is helpful in understanding the removal mechanism and designing an effective wetland for the removal of suspended solids.

Studies have shown that the particle size distribution of surface water was pH dependent on the pH, temperature and flow discharge <sup>[7]</sup>. Most (> 95%) of the suspended sediment transported by rivers was < 63  $\mu$ m, with the < 2  $\mu$ m fraction typically accounting for between 15 and 25% <sup>[5]</sup>. Aggregates are likely to increase the particle sedimentation velocity and the retention time of clay particles was not constant in a constructed wetland <sup>[8]</sup>.

There were four main aims of this study:

(1) to determine the particle size distribution and analyze the characteristics of the particles distribution in a wetland surface water; (2) to reveal the functions of different sized particles in the mechanisms for the formation of turbidity and total suspended solids (TSS); (3) to examine the particles removal efficiency and analyze their characteristics; (4) to analyze the effects of ADD in the wetland. **2. Materials and method** 

The studied wetland was located in Janghwa-do, Gimje city, on the west coast of Korea. The wetland covers an area approximately 7,800 m<sup>2</sup>, with a maximum treatment capacity of around 2275 m<sup>3</sup> and watershed area of approximately 75 ha, which is mostly rural, primarily rice paddy, with some isolated single-family housing and forest. Two sedimentation ponds were designed in the wetland, one after the inlet and the other just before the outlet, with the inside designed to have both deep and shallow water wetlands (Figure 2).



Figure 2. Schematic diagram of the wetland in this study.

The monitoring period was the first year after the wetland had been put to use; the vegetation area was no more than 30% of the total wetland, and mostly located at the two banks. The water depth was stable, at no more than 80 cm during dry days.



Figure 3. The hydrograph during the sampling period.

On dry days, both inflow and outflow samples, for base flow, were collected 6 times from June 9, 2009 to September 5, 2009. The sampling and weather information are summarized in Figure 3 and Table 1.

Most of the rainfall (around 50%) occurred in summer with a higher temperature, and the antecedent dry days ranged from 2 to 6 days. All samples were immediately analyzed for their particle size distributions using an AccuSizerTM 780A particle analyzer. In this study, only particles ranging from  $0.51~30 \ \mu m$  were analyzed due to



the error and indeterminacy caused by the sedimentation for coarse particles. Continuous recording of the flow at both the inlet and outlet as well as of the precipitation were measured.

 Table 1 Summary of the information for samples on dry days

			·			
Item	E1	E2	E3	E4	E5	E6
Date	06/09	07/01	07/21	08/11	08/26	09/05
ADD	5	2	2	3	6	6
Rainfall (mm)	6.5*	14.5*	3*	16*	23*	21*
Intensity (mm/hr)	3.3*	3.0*	1.0*	2.3*	4.6*	2.6*
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\*: the value of last rainfall event.

## 3. Results and Discussion

### 3.1. Particle Size Distribution

Figure 4 shows the particle size distribution in the wetland surface water during dry days. Generally, the particles in the inflow were coarser than those in the outflow, which was due to the sedimentation of coarse particles and the resuspension effects of fine particles during the transportation in the wetland.

The only exception was for event E2, where the particle size distribution was contrary to this rule, which can be explained by the following: the base flow was quite low around the sampling day; thus, some floatable organic matters was trapped around the corners close to the outlet due to wind and waves, and the adsorption of fine particles to organic matter resulted in the coarser particle size distribution at the outflow.



Figure 4. The particle size distributions on dry days.

#### 3.2 Particle in Different Size Range

Y. Li measured the particle size distribution on a lab-scale

constructed wetland; the results indicated that the particles became finer along the experiment channel, which was in partial agreement with the results in our study <sup>[9]</sup>. There have been no reports on the particles in the outflow being coarser than those in the inflow, maybe due to the difference between the natural and constructed lab-scale wetlands; the particle size distribution will change under different hydraulic loads and surrounding conditions in a natural wetland <sup>[10]</sup>.

Figure 5 gives the volume and number fraction of particles in different size ranges; in general, fine particles  $(0.51 < d < 2 \mu m)$  occupied a low volume fraction, although they accounted for a high number fraction, more than 90% of particles based on the number occupied no more than 9% of the volume fraction for particles less than 2  $\mu m$ . In contrast, particles coarser than 4  $\mu m$  accounted for around 80% of the volume fraction, but no more than 5% of the number fraction. This is natural because the particle volume is proportional to the cube of the particle size, with slight variations due to shape factors.



Figure 5. The number and volume fraction of the inflow and outflow on dry days. (a): number fraction, and (b): volume fraction.





Figure 6. Relationships between the particle concentration and TSS/turbidity.

Therefore, it can be concluded that the particles volume is mainly dependent on particles coarser than 4  $\mu$ m, although they have a smaller number fraction.

Figure 6 indicates the relationship between the particles concentration and the TSS & turbidity for different particle size ranges. In summary, there was a close correlation between the particles number concentration and TSS & turbidity, and this relationship differed for TSS and turbidity. For turbidity, the relationship was particularly evident for particles less than 10 µm, which can be explained by the turbidity being primarily caused by suspended matter, although soluble colored organic compounds can also contribute <sup>[3]</sup>, and is mainly dominated by light scattering due to particles in the range of 1 to 6 µm that have a larger surface to volume ratio <sup>[11]</sup>. Conversely, TSS is more likely to be affected by particles coarser than 4 µm, which is in agreement with the number and volume fraction characteristics, assuming an average particles density (Table 2 and Figure 6), and with the results obtained for an aquacultural effluent <sup>[12]</sup>.

However, the number for particles coarser than 20  $\mu$ m compare to fine particles can be ignored (Figure 5), and there was a dramatic error in the determination of coarser particles due to fast sedimentation during the measurements; thus, the relationships between particles coarser than 20  $\mu$ m and the TSS is unclear, but the TSS are actually positively related to coarse particles.

The relationship between the particle concentration and water depth was analyzed (Figure 7), with a close correlation observed between a higher water depth and a low particle concentration based on the number, which can be explained by the following: the water depth is the factor controlling resuspension; therefore, a low water depth is more likely to be affected by the resuspension of sediment and disturbance from vagrant benthos <sup>[3]</sup>, which is also related to the retention time because the lower the water depth, the shorter the retention time.



Firgure 7. Relationship between the water depth and particle concentration.

# **3.3.** The Seasonal Difference of Particles Concentration

On dry days, the wetland inflow (actually baseflow) embodies annual differences due to the weather conditions, and the wetland water is a function of the internal ecosystem process, where some random physical and biological events can result in short-term effects on the physical and chemical composition of the wetland water. Therefore, the particles in the surface water of a wetland will exhibit annual variability. The wetland displayed peak TSS and particle concentrations in summer during the studied period (July to September) (Figure 8). Many rainfall events and high temperatures were known to be concentrated in this period (Figure 3), which resulted in algal blooms and the entry of particles into the wetland with runoff water, which explains the seasonal characteristics of the TSS and particle number concentration.



Figrue 8. The seasonal differences in the TSS and particles concentration.

### 3.4. Particles Removal Efficiency



Under turbulent conditions, the particles removal efficiency can be determined by the following equation <sup>[8, 13]</sup>:

$$E = 1 - \exp(-\omega A Q^{-1}) \quad (1)$$

where A is the surface area, Q the flow rate in the wetland and w the terminal sedimentation velocity, which can calculated using Stokes' Law:

$$\omega = \frac{d^2(\rho_{solid} - \rho_{water})g}{18\nu} \tag{2}$$

where *d* is the particle diameter,  $\rho$  solid- $\rho$  water the density difference between the particle and water, *g* acceleration due to gravity and v the kinematic viscosity of water.

In this study, the average water temperature and wetland surface were estimated to be  $20 \sim 30^{\circ}$ C and  $4000 \text{ m}^2$ , respectively, on the sampling days, with the specific gravity of particles set at 2.65 g  $\cdot$  cm<sup>-3</sup>. The average hydrology load was estimated to be around 1 m/d on dry days. The observed removal efficiency was determined based on the particles number, with the theoretical value calculated using the Eq.1, the results of which are shown in Figure 9.



Figure 9. The particles removal efficiencies on dry days.

Actually, there was an error with particles smaller than 2  $\mu$ m due to the density difference using the theoretical equation; particles in this size range are defined as colloids, whose densities are generally less than 2.65 g cm-3. Therefore, a big difference was still evident between the observed and theoretical values for particles coarser than 2  $\mu$ m; the observed values were much lower than the theoretical values. This was because the theoretical method does not consider the effects of resuspension, adsorption and release, which play important roles in the wetland surface water.

The time taken for a particle to fall a vertical distance (h) is determined from its terminal velocity (w):

$$t_{fall} = h / w \quad (3)$$

where h is the water depth and tfall the time to fall. If the water is moving through a wetland length (L) at velocity (u), the time of travel is:

$$t_{travel} = l/u \quad (4)$$

where L is the wetland length, time to travel wetland and u the actual water (flow) velocity.

Theoretically, all particles of a size corresponding to a given fall velocity will be removed due to settling if the travel time exceeds the settling time  $(t_{travel} > t_{fall})$ , which means the particles removal efficiency would be constant and increase with increasing particle size due to their relative density without considering the other effecting parameters in the wetland (Figure 10, line A and B). The difference between A and B is determined by the retention time; the removal efficiency can be characterized by B if the retention time is long enough; otherwise, it can be characterized by A. However, based on the results for the removal efficiency in this study, the particles behavior in the wetland surface water can be defined in two parts due to other effecting parameters, such as resuspension, adsorption and release, etc (Figure 10, line C), where the first part describes the colloids behavior and the second the coarser particles. The turning point (dt) ranges from 2 to 4  $\mu$ m, which is just within the colloids range, and depends on the hydraulic conditions in the wetland.



Figure 10. Schematic diagram of the removal efficiency with particle size.

#### 3.5. Effects of ADD

Antecedent dry days (ADD) are an important parameter affecting the wetland behavior related to the flow rate, water depth and retention time, etc. Accordingly, ADD affect the particles removal efficiency. The relationships between ADD and the removal efficiency based on the TSS, turbidity and particles number were analyzed in this study (Figure 11). It was clear that ADD were positively related to the removal efficiency; the shorter the ADD, the lower the removal efficiency. Shorter ADD are known to be associated with much rainfall runoff, which



leads to a shorter retention time and; therefore, to lower removal efficiencies of turbidity, TSS and particles.

 $D_{50}$  and the uniformity coefficients (U, which defined as the  $D_{60}/D_{10}$ ) are always used to describe the particles size and uniformity; therefore, the relationship between  $D_{50} / U$  and ADD was analyzed for baseflow in dry days (Figure 12). The results indicated that ADD were positively related to both  $D_{50}$  and U, which means that the shorter the ADD, the finer the particle size distribution and the lower the uniformity, because low ADD implies more rainfall, and this rain will dissolve the particles on the surface of surrounding farmland and roads, and these dissolved fine particles are washed into the wetland <sup>[14]</sup>, resulting in the lower  $D_{50}$  and uniformity coefficient (U).



Figure 11. Relationship between the removal efficiency and ADD.



Figure 12. Relationship between D50/U and ADD.

# 4. Conclusions

Samples collected from wetland surface water on dry days were analyzed, and the results indicated that particles were finer in the outflow than the inflow due to the sedimentation of coarse particles and resuspension of fine particles in the wetland on dry days. Therefore, it can be concluded that the sedimentation, resuspension, adsorption and release occurring in the surface water of the wetland played important roles, as they affect the particles behavior, especially that of particles less than 30  $\mu$ m.

On dry days, the volume fraction of fine particles (less than 2  $\mu$ m) was no more than 9%, although they occupied more than 90% based on the particles number; the corresponding values for particles less than 4  $\mu$ m were 22 and 96%, respectively. Particles with different size ranges play different roles in their contribution to the turbidity and TSS values; turbidity is mainly related to particles less than 10  $\mu$ m; whereas, TSS are generally dependent on particles coarser than 4  $\mu$ m, which is in agreement with the volume fraction. The TSS and particles number concentration exhibited seasonal differences, with a peak observed in summer.

Unlike traditional sedimentation theory, there was a turning point for the removal efficiency of particles less than 30  $\mu$ m, which lies within the range of 2~4  $\mu$ m, i.e. the colloids limit value. The observed removal efficiency based on the particles number was lower than the values obtained based on sedimentation and the hydrology load, due to the effects of resuspension, adsorption and release in the wetland.

Antecedent dry days play an important role in the wetland, and are positively related to the removal efficiencies of turbidity, TSS and particles in the wetland, which also affects the particle size distribution and uniformity coefficients.

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