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# Transport in a three-zone wetland: Flow velocity profile and environmental dispersion

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ABSTRACT

To achieve better understanding of transport process in real waterways interacted with adjacent aquatic vegetation and riparian buffers, a three-zone model featuring the bank-effect is presented to character the water flow and environmental dispersion. Based on basic formulation in context of porous media flow, the velocity profile of a fully developed flow through the wetland is derived, with that for single zone and two-zone wetland flows recovered as special cases. The environmental dispersivity is determined by the approach of multi-scale analysis, with the effects of dimensionless parameters well illustrated. Application examples are provided to illustrate associated hierarchical structure for the critical length and duration of the contaminant cloud, and a comparison is made between the three-zone wetland and a corresponding three-layer wetland.
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## 1. Introduction

Wetlands can provide significant ecological services including water supply, water quality improvement, wildlife conservation, climate regulation, etc. [1–3]. For ecological risk assessment, ecological restoration and wastewater treatment engineering associated with wetlands, either natural or constructed, a fundamental issue is the contaminant transport characterized by environmental dispersion [4–8].

Numerous endeavors have been contributed to understanding the mechanisms of solute dispersion in water bodies since the reputable work of [9]. The concept of Taylor dispersion refers to the process that dissolved contaminant disperses towards longitudinal direction under the combined action of lateral solute diffusion and the transverse non-uniformity of the longitudinal velocity [9], and it has been extended for a variety of environmental flows including those in wetlands, rivers and estuaries [4,10–15]. Elder investigated the dispersion in a channel of constant depth, which revealed that both the depth and shear velocity contribute to the dispersion coefficient [10]. Fischer analyzed the mechanisms of transporting the dissolved constituents in oscillatory, estuary flow, and found that the dispersion coefficient can sometimes be negative [16]. Guymer conducted a series of laboratory experiments on a large scale channel with sinuous planform geometry, indicating that the more 'natural' cross-sectional geometry channel exhibits strongly skewed distributions associated with an increase in the value of a longitudinal dispersion parameter [17]. Kashefipour and Falconer developed an equation, which relates

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dispersion coefficient to the hydraulic and geometric parameters of the flow, for predicting the longitudinal dispersion coefficient in riverine flows [18]. A technique for predicting the longitudinal dispersion coefficient is proposed by Seo and Baek based on the beta function for the transverse velocity distribution in natural streams [19]. Wu and Chen recently explored the mechanism of approach toward transverse uniformity of concentration distribution, providing new physical insight into Taylor dispersion [20,21]. However, these researches were conducted for pure fluid flows, without the effect of aquatic vegetation on dispersion into consideration.

Ubiquitous in rivers, estuaries and wetlands, vegetation strongly influence water conveyance and mass transport, introducing more complex mechanisms to the dispersion process [22]. *Järvelä* carried out flume studies to investigate flow structure around flexible vegetation, the result of which showed that the flow above the wheat reasonably followed the log law [23]. Lightbody and Nepf's work clarified that profiles of vertical velocities within emergent vegetation are directly influenced by the distribution of the vegetation elements [24]. For the emergent and submerged natural vegetation in open channel flow, Shucksmith explored the longitudinal dispersion coefficients [25]. The above experimental and field measurement researches were mainly limited to the mean and turbulent flow and mass transport in the presence of aquatic vegetation, associated with micro-dispersion in terms of phase average based superficial diffusion as Taylor dispersion in the micro-flow in the porous media. However, in the environmental area, what we concern most is the Taylor dispersion at the environmental scale, namely the environmental dispersion, which is a kind of macro-dispersion out of standard environmental and risk assessment. Attributing to the presence of aquatic vegetation, the micro-dispersion becomes more complex, inevitably resulting in different apparent characteristics of macro-dispersion at the environmental scale. Both the micro-dispersion and macro-dispersion are affiliated to Taylor dispersion, but the key points are the distinctiveness of the involved scales. In context of mechanics for porous media flows, Chen and his collaborators defined and explored the environmental dispersion in terms of porous media in single-channel wetland flows dominated by the depth-, width-, and depth-and-width-effects, using Aris' method of concentration moment or the method of multi-scale analysis [15,26–31]. By considering the effect of inhomogeneous distribution of vegetation in wetlands, Wu et al. [32] explored the environmental dispersion in wetlands with two zones that are distinctly vegetated, resorting to the approach of concentration moments. As the extension of the modeling on contaminant spreads in a single-layer wetland with homogeneous vegetation [27], Chen et al. [4] analyzed the environmental dispersion in two-layer wetlands with layered vegetation. The critical length and duration of the contaminant cloud are presented, which give apparent results of dispersion at the concerned environmental scale.

Vegetation occupied in wetlands is mostly characterized by different canopy and stem morphology. Nepf [7] made filed and experimental observations for the flow and mass transport in the presence of vegetation at the micro-scale. The characteristics of velocity and turbulent in micro-region inevitably bring influences on the apparent environmental dispersivity at the concerned environmental scale. As an analytical effort, Wang et al. [33] investigated the flow and environmental dispersion in a three-layer wetland dominated by free-water-surface-effect. By Aris's method of concentration moments, the asymptotic variation of the dispersivity is concretely illustrated.

Waterways are highly interactive with the adjacent riparian buffers [34]. Typical examples are wet meadows dominated by herbaceous plants that are usually water-emergent or water-submergent on either side of the flow [35], and the river along with riparian vegetation during overbank flows in the rainy season [36]. It is well documented that vegetated riparian zones can strongly influence the hydraulics of the entire channel due to the invasion of gravels and stems [36]. Riparian vegetation consequently strengthens the flow in the resulting narrowed channel. An awareness of the flow and dispersion under the effect of multi-channel and spatial-structural vegetation in the wetland is essential for understanding the transport of pollutants in open channel flows. Different from the three-layer model featuring the wetlands dominated by layered

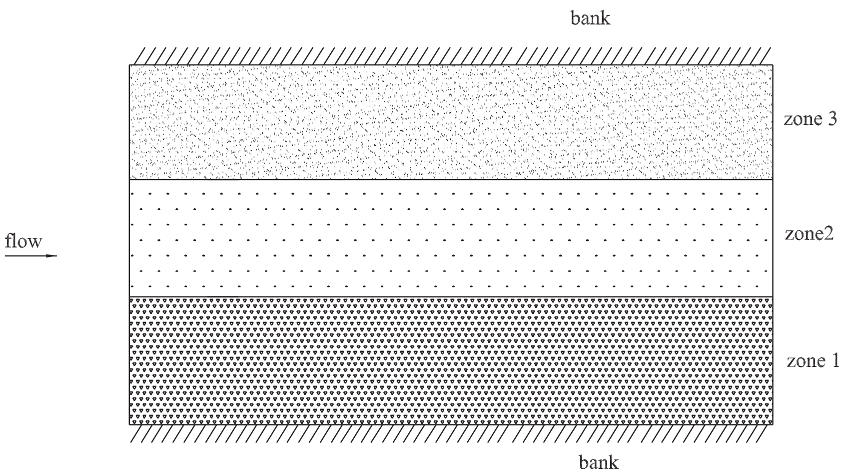


**Fig. 1.** Sketch for a three-zone wetland.

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