Applying Hyporheic Exchange Transient Storage Concept to Quantify Sediment Transport Processes on the Landscape

C. Huang[1], S.K. Nouwakpo[2], Z. Li[3]

There are many different models that have been developed to quantify erosion and sediment transport processes on the landscape. Some models are very detailed for specific erosion or sediment transport processes, e.g., soil detachment under wind-driven rain, rain-impacted flow transport (RIFT), interrill/rill erosion, gully bank sloughing, tunnel erosion, headcut migration, and sediment transport in rivers, etc. On the other hand, there are also landscape evolution models, based on topographic and hydrologic attributes, to quantify erosion/deposition as well as rill/channel network evolution. Although some of these models do involve subsurface hydrology, most of the models dealing with sediment movement on the landscape are mainly driven by surface hydrology and flow hydraulics.

In the development of process-based erosion models, the concept of sediment transport capacity (Tc) becomes the primary criterion in determining whether erosion or deposition occurs. The underlying concept is that for specific flow hydraulics and sediment properties, there is a quantifiable Tc. If the sediment load (Qs) is less than Tc, the flow will have additional eroding power until the transport capacity is filled. Conversely, if the sediment load is greater than Tc, deposition occurs. In the Water Erosion Prediction Project (WEPP) model, the detachment-transport coupling is further quantified by the first-order reaction equation where the detachment rate is proportional to the transport capacity deficit, i.e., Tc-Qs. This type of quantification is somewhat intuitive without any rigorous experimental proof.

In recent years, we have attempted to measure sediment transport capacity under controlled experiments where a 5-m long soil box was fed with run-on water with different amounts of sediment. We intentionally forced the 5-m soil bed to shift from a net erosion to a net deposition regime as we increased the sediment feed rate. During the experiment, the soil erodibility was increased by changing the subsurface hydrology from free drainage to saturation and then upward seepage. Our results show that erosion was increased and deposition decreased as the subsurface moisture was shifted from drainage (Dr) to saturation (Sa) and then seepage (Sp). The shift from Dr to Sa to Sp also resulted in an increased total sediment delivery as well as crossing the point from the net erosion to the net deposition regime. The crossing from net erosion to net deposition is the situation when the sediment feed rate (input) is the same as the sediment delivery (output), hence neither erosion nor deposition occurred overall. In conclusion, we are able to find an equivalent Tc (when run-on sediment = Qs) based on the Tc-Qs coupling concept, but the equivalent Tc value varies as subsurface hydrology is changed while the flow hydraulics (flow depth, width and velocity measured during the experiment) and sediment properties remain the same.

While working on hyporheic exchange processes, we came across the transient storage model concept for solute transport on the landscape. This model treats the hyporheic zone as an active source and/or sink for solutes being transported in a stream, hence the term 'transient storage'. This model has separate hydrodynamic transport, source and sink terms. The source

[1]Chi-hua Huang, Soil Scientist, USDA-Agricultural Research Service, National Soil Erosion Research Laboratory, West Lafayette, Indiana, USA; [2]Sayjro K. Nouwakpo, Research Scientist, University of Nevada-Reno, Reno, Nevada, USA; [3]Zhaoxia Li, Professor, College of Resources and Environment, Huazhong Agricultural University, Wuhan, China. Corresponding author: C. Huang, email: chi-hua.huang@ars.usda.gov.

and sink terms can be driven by the subsurface hydrology or through either active or passive interactions between the substrate and the water column. It becomes apparent that the transient storage solute transport model concept can be readily translated to sediment movement on the landscape where it provides the storage function for sediments when they are not being transported. The hydrodynamic transport term handles the movement of suspended sediments. The subsurface flow driven process contributes to tunnel erosion and bank failure. The water column and substrate interactions can be interpreted as erosion and deposition processes. Since both surface and subsurface flow and transport processes are considered in the transient storage model, it can be used to quantify a range of sediment transport processes from hillslope erosion when surface hydrology is dominating to landslide and debris flow when subsurface hydrology becomes the primary driving force.

Instead of presenting solid proof that the hyporheic exchange transient storage model for solute transport is valid for application to sediment movement on the landscape, our intention in this presentation is to bring forward discussions on how to move beyond the detachment-transport coupling concept used in current process-based erosion models.