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Session 1C: Student Research Projects

Kentucky Water Resources Research Institute, University of Kentucky

A 3-D COMPUTATIONAL FLUID DYNAMICS CODE
FOR SIMULATION OF PUMP STATIONS WITH
VERTICAL PLUNGING JET AND AIR BUBBLE TRANSPORT

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Abstract

Pump stations with plunging jets are traditionally tested using scaled models. Scaled models are expensive to construct and time consuming to test. The use of computer aided modeling, better known as computational fluid dynamics (CFD) is another approach to study such problem. Commercial CFD packages can be used to solve for the hydrodynamics and turbulence in a pump station, but lack the capability to model air bubble transport from plunging jets. This work attempts to tie together the modeling of hydrodynamics and air bubble transport from a plunging jet.

This study was performed based on the use of CFD to model air bubble transport of a plunging jet, normally seen in pump stations. A finite volume numerical based solver was used along with the dynamic subgrid scale model to simulate the hydrodynamics and turbulence. Effects of the air bubbles drag force to the flow field due to its upward motion was integrated into the source terms of the Navier-Stokes equations. A modified transport equation was used to track the migration of air bubbles from the plunging jet. The modification involves coupling the rising velocity of the air bubbles with the local velocities in the flow field.

Preliminary results from this work will be presented and compared to published data. For applications such as pump station modeling, where microscopic details of the air bubbles are unnecessary, this approach may be a cheaper alternative for air entrainment modeling and associated applications.

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CHEMICAL EVOLUTION OF GROUNDWATER IN THE WILCOX AQUIFER OF THE MISSISSIPPI EMBAYMENT

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We are integrating solute analyses and numerical modeling to evaluate groundwater residence time and chemical evolution within the confined Wilcox aquifer of the northern Gulf Coastal Plain. This study focuses on a broad regional flow path extending ~ 325 km from the subcrop of the Wilcox Group in southeastern Missouri to the farthest downgradient municipal wells in eastern Arkansas. We sampled 21 wells in the Wilcox aquifer, six wells in the overlying Claiborne aquifer, and one well in the underlying McNairy-Nacatoch aquifer, with depths ranging from 116 to 518 m. Along the regional flow path, we observed increases in temperature (consistent with increasing depth), pH, and CH_4; decreases in Mn and SO_4^{2-}; a prevalence of Fe (18 wells > 0.3 mg/L); and a lack of O_2 (27 wells ≤ 1.0 mg/L) and NO_3^- (undetectable in 23 wells). Ca^{2+} concentrations gradually decreased as Na^+ increased. We infer that upgradient calcite dissolution, downgradient cation exchange, redox reactions, and (possibly) cross-formational mixing control solute chemistry. Values of δ^2H and $\delta^{18}O$ (-42 to -28‰ and -6.8 to -5.1‰, respectively, relative to the V-SMOW standard) fall along a regional meteoric water line (MWL) for Paducah, Kentucky, and are slightly enriched with respect to the global MWL. There are two distinct, gradual enrichments in these stable isotopes along the flow path. One plausible explanation for the north-south increase in values is increasing proximity to the moisture source area (the Gulf of Mexico). A second, but not exclusive, explanation is depletion of the isotopic composition of recharge over time. Use of ^{36}Cl and temperature in numerical models of groundwater flow coupled to solute transport and heat flow will test the aforementioned explanations.

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SEDIMENT ORGANIC MATTER DEGRADATION WITHIN STORAGE ZONES DEPOSITED IN-STREAM

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Non-point source sediment pollution of fine sediments (silt- and clay-sized particles or aggregates) threatens the continued health and vitality of surface waters in Kentucky. In order to address these concerns, sediment transport studies at the watershed scale aim to identify principal sediment sources for affected rivers and streams in order to develop watershed optimization techniques. Sediment fingerprinting is one such method to identify sediment source and estimate the contribution of each source to the total sediment loading.

In the past, sediment fingerprinting has utilized primarily inorganic tracers of sediment due to their conservative nature. More recently, sediment fingerprinting studies have explored using indicators of sediment organic matter (SOM) including total organic carbon (TOC) elemental percentage, total nitrogen (TN) elemental percentage, stable carbon and nitrogen isotopes (δ^{13}C and δ^{15}N), and the carbon to nitrogen atomic ratio (C/N) as natural sediment tracers to study fine sediment transport processes. If well understood, these tracers can provide information regarding not only sediment source but also sediment erosion and transport processes. TOC, TN, C/N, δ^{13}C, and δ^{15}N have been shown to be conservative in small watersheds over short periods of time. However, SOM stored in-stream can undergo degradation via biological processing of the organic matter due to the active microbial community thereby causing the tracers to be non-conservative over larger spatial and temporal scales. This degradation limits the use of organic tracers because SOM decay is not well understood due to the limited information available regarding the in-stream microbial pools. Ecological variables affecting microbial processing include water temperature, algal biomass, water chemistry (pH), oxygen and nutrient concentrations, and turbidity. In the context of sediment transport studies, these variables are further complicated by varying watershed parameters (e.g. climate, geology, topography, and land-use) and multiple upland erosion sources.

The objective of this study was to investigate the microbial degradation of TOC, TN, C/N, $\delta^{13}C$, and $\delta^{15}N$ in a large watershed with in-stream sediment storage by isolating ecological variables affecting microbial processing of organic matter in-stream. To accomplish this, a watershed was carefully selected that exhibits one primary sediment source and limits the impact of watershed parameters on sediment transport processes. The study site chosen is a headwater reach of the South Elkhorn Watershed near Lexington, Kentucky. The primary erosion source within the watershed is streambank erosion, and in-stream sediment storage is common. Suspended sediment samples and erosion source samples were collected at multiple sites over a nine-month sampling routine to represent the tracer distribution in the watershed both spatially and temporally. All samples were analyzed for TOC, TN, C/N, $\delta^{13}C$, and $\delta^{15}N$ using an elemental analyzer and an isotope ratio mass spectrometer. In addition, microscopy techniques were utilized to study physical aggregate characteristics and the influence of algal biomass on tracer variation. Sediment load and flowrate were also measured.

Results of the study showed distinct seasonal variations for SOM reflective primarily of seasonal effects on microbial processing. TOC and TN values are lower in the warmer summer months as compared to the cooler spring months, and $\delta^{13}C$ and $\delta^{15}N$ are enriched for the summer as compared to the spring. Both of these trends indicate decomposition of SOM within sediment storage zones in-stream during the summer months when microbial activity is higher. Spatial and hydrologic trends are not as prominent, indicating a successful isolation of microbial processing of SOM as opposed to watershed parameters dictating SOM tracer signature.

In addition, a suspended sediment source and fate un-mixing model is being developed to further study organic decomposition of SOM within in-stream storage zones. The un-mixing model will estimate the erosion rates of streambank sediment and will be complemented with shear and settling parameters for sediment stored in-stream. A better understanding of the linkage between sediment residence time in stream and SOM degradation will improve watershed-scale sediment transport studies by providing a correction factor for organic degradation when utilizing SOM properties as tracers in sediment fingerprinting studies.

EFFECTIVENESS OF IMPROVED SKID TRAIL HEADWATER STREAM CROSSINGS

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One of the primary concerns associated with timber harvesting is the production of sediments from stream crossings. While research has shown that using improved haul road crossings can mitigate sediment production in perennial streams compared to the use of unimproved crossings little research has been undertaken on temporary skidder crossings of headwater streams, a situation common to a significant percentage of ground skidding operations. This experiment consisted of a controlled replicated testing of the effectiveness of four types of temporary skidder stream crossings (unimproved ford, corrugated culvert, wood panel skidder bridge, and PVC pipe bundle) relative to bed load and suspended sediment production. Automated samplers were used to monitor sediment and bedload production during the construction, use, removal, and post-removal phases associated with the use of these temporary crossings. Results showed that improved crossings mitigated total sediment production compared to unimproved fords. Further, wood panel bridges yielded lower amounts of sediment than culverts but PVC pipe bundles show no difference between bridges or culverts. Sediment production varied by crossing type and use phase. While no differences were found among crossings types during construction, there was a difference between improved crossings and fords during use. Further, bridges and PVC pipe bundle crossings produced significantly less sediments than culverts during both their removal and during post-removal sampling and fords produced the largest amount of sediments during these phases.

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