DEVELOPMENT OF THE RIVER ANALYSIS TOOL (RAT): COMPARISON OF PREDICTED BED CHANGES TO ADAPTIVE HYDRAULICS MODEL (ADH) RESULTS

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Abstract Development of the River Analysis Tool (RAT) required validation through comparison of predicted results to the results of a physics based sediment transport numerical model. The objective of this paper is to present comparisons between bed changes predicted by the RAT and the results of the Adaptive Hydraulics Model (ADH), a fully coupled hydrodynamic and sediment transport 2-dimensional numerical model. Comparisons are necessary to determine consistency and morphological predictability of RAT results. Typically, multi-dimensional sediment transport models are prohibitively resource intensive for the analysis of long term (50+ years) bed changes due to control structures or other imposed changes. RAT is a forecasting tool developed to predict long term trends in river morphology and short circuit computational burdens associated with a multi-dimensional model for lengthy simulation periods. Reliability of RAT is dependent on the validated multi-dimensional hydrodynamic models, which currently include ADH and Mike 21. Short term runs of the multi-dimensional model are used to develop bed rating curves that indicate the scouring or shoaling potential of a single cell for a given flow. By simulating several flows in the hydrodynamic model, RAT is able to determine bed changes over multiple annual hydrographs and make future morphology predictions. Ultimately, RAT is not a transport model but an assessment tool that watershed managers can use to estimate long-term response to river alterations. This allows more effective planning of rehabilitative measures and management of the resource to meet ecological objectives.

INTRODUCTION

The River Analysis Tool (RAT) is a system that attempts to combine the decoupled hydrodynamic and sediment responses to morphological evolution; while bridging the computational limitations of multi dimensional modeling with the required temporal requirements of morphological changes. Applying both disciplines of fluvial geomorphology and hydraulic engineering/sediment transport is imperative in understanding complex river responses by 'bridging principles' of these disciplines (Wolman and Gerson 1978).

The primary variation between theoretical fluvial geomorphology and hydraulic engineering is the former evaluates the fluctuation of landform while the later is based on the physical process of flow forces (Soar and Thorne 2001). Fundamentally, fluvial geomorphology is the scientific evaluation of land forms produced by a river. Likewise, "sedimentation engineering embraces the identification, planning, analysis, and remediation, principally in context of civil and hydraulic engineering practice, of projects or technical investigations to avoid and/or mitigate

problems caused by sedimentation processes" (ASCE 110). Both studies play important roles in attempting to understand the evolution of river dynamics.

Spatial and temporally variations/views exist between engineers and geomorphologists that merit evaluation. This is in part due to "adjustment processes that display a variety of spatial and temporal patterns and operates over a wide variety of time scales" (ASCE 1998, pg 884). Briefly, there are three time scales that geomorphologists reference (Watson et al. 2005). First, geologic time references thousand to millions of years during which significant changes occur. Additionally, modern time refers to decades to centuries with geological adjustments occurring. Lastly, present time is years to decades with the occurrence of minimal geological changes. Conversely engineers generally evaluate systems on an extremely shorter scale, on the order of seconds to days. From those "short term" evaluations design management decisions are made. However, morphological changes from projects require monitoring and evaluation over a period longer than years (Watson et al. 2005). For example to this day cutoffs that were constructed in the 1930's along the Mississippi River still cause river adjustments (Biedenharn 1995; Biedenharn and Watson 1997).

Beyond the temporal is the spatial scale that requires an additional evaluation to properly include the required study area. Generally extending the boundary conditions beyond the study area is desirable and allows the flow and transport characteristics to adjust properly before entering the area of interest. Furthermore, the larger the domain the more likely other areas outside the study site that pose problems will be illuminated. For geomorphologists who generally consider the larger scale land forms changes large spatial scale is imperative; however, engineers typically only evaluate local systems although they might have huge regional impacts. With engineers using numerical models the runs/computation time required to run multiple years on larger domains is cumbersome and often not practical. Therefore, required is a methodology for linking long term simulations for morphology estimates based on physics until further advances in numerical modeling and computational times are advanced.

Several approaches have been developed to address the above issues. As related to estuaries the evaluation of morphological evolution was categorized by Savant (2008) as one of the three areas 1) Trend Analysis, 2) Regime-Type Analysis, and 3) detailed process simulation. Furthermore, relevant to rivers, the ASCE Task Committee (1998) outlined morphological evaluations as methods including 1) empirical equations 2) extremal hypothesis, and 3) rational or mechanistic approaches. Additional, future predictors include statistical and mathematical models. The RAT lies in a specialty category since it uses a multidimensional model to develop the regressed equations, although fundamentally it lies in the trend analysis or empirical equation approach. By using the multidimensional model to develop the sediment trends the RAT creates a quasi-numerical model.

PURPOSE

The purpose of this work is to determine the usability and reliability of the River Analysis Tool. It is applied as a forecasting tool to enable watershed managers the ability to predict potential complications from designs. Often decisions made might cause immediate effects on the system or might not cause any effects till years after the project completion (Savant 2008).

Understanding and allowing an appropriate amount of time for system development is necessary to determine the success/performance of a project (Watson et al. 2005). For this study the demonstration site is the Kate Aubrey Reach of the Mississippi (located north of Memphis and shown in Figure 1). The model is run for a year using ADH and is used as the base comparison. Additional steady state runs are made and the simulations output are used to constructed bed rating curves in RAT. Then the same hydrograph in the ADH model is applied in the RAT to simulate the bed change. Upon completion of both, comparisons are made to determine RAT's reliability.

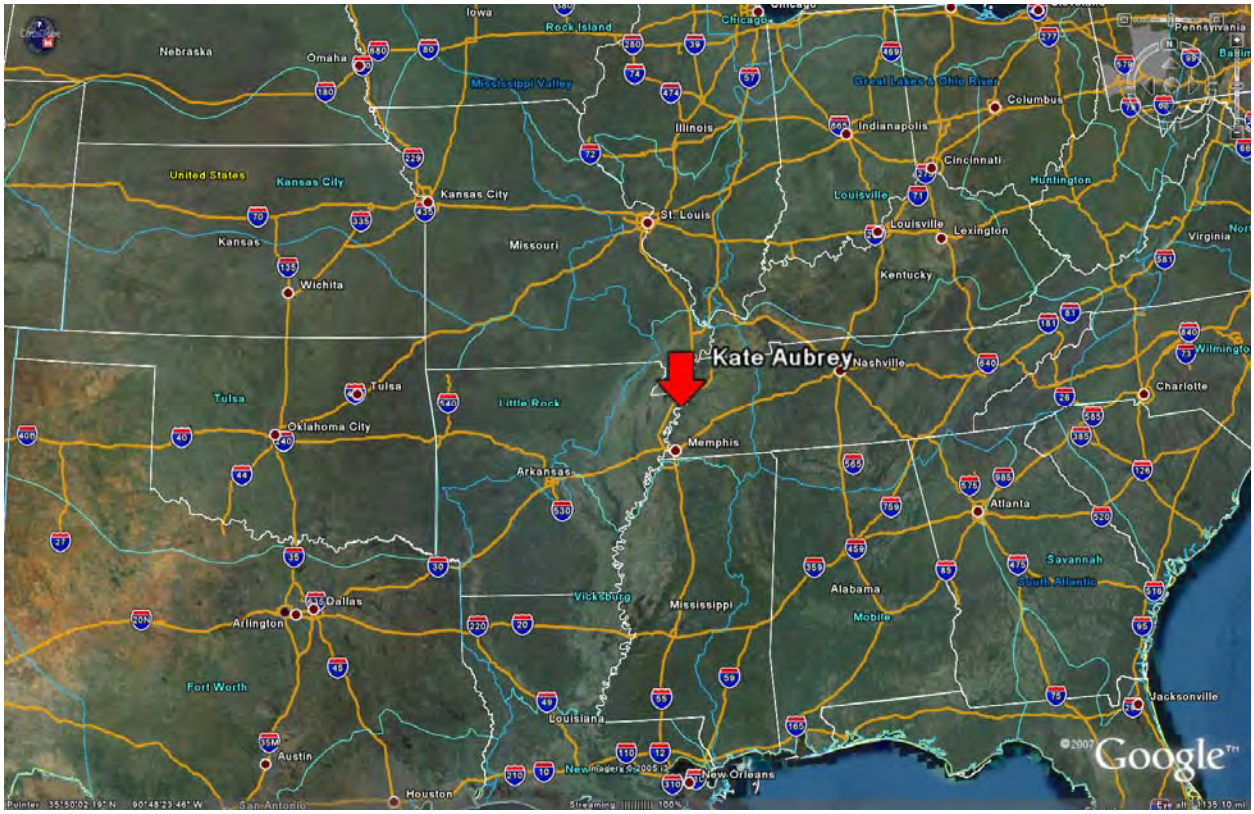

Figure 1 Location map of the Kate Aubrey reach (Google Earth Image).

STUDY AREA

The Kate Aubrey reach of the Mississippi River is selected as a test site since there is a pre-existing 2-D simulation. Description of the initial study is found in the System-Wide Water Resource Program Technical Note, ERDC TN-SWWRP-06-6, by Tate and Berger (2006). As stated in the note this particular reach is ideal since there are two dike configurations each with its own survey (1975 and 1999) of which the later one worked and the former did not (Tate and Berger 2006). This allows for a location where multiple geomorphic analysis are possibility for future exploration and development of the RAT.

Figure 2 Kate Aubrey Reach of the Mississippi River (Google Earth Image).

As shown in Figure 2 this section of the river has multiple dikes and bendway weirs that are actively maintaining the navigation channel. Locations behind the dikes are showing areas of deposition by which the ADH model can be visually validated.

ADAPTIVE HYDRAULICS MODEL

Prior to further explanation of the RAT it is important to understand the usability and functionality of the Adaptive Hydraulics Model (ADH). As the name implies the model is adaptive, in that it can split both the time step and element to help convergence and capture necessary details of the hydraulics. This minimizes grid convergence tests and can increase simulation accuracy. Although still under development, developers have made great strides in the capabilities of the program. It is based on a library system that allows the implementation of new subroutines without major code reconstruction. Basically "ADH can describe both saturated and unsaturated groundwater, overland flow, 3D Navier-Stokes, and 3D Shallow Water problems along with the 2D shallow water equations" (ADH 2008, page 2). The model does interface with the Surface Water Modeling System (SMS) allowing for rapid dissemination of output data. In order to run the model three files are required; mesh file, boundary condition file, and hot start file. Obviously the boundary condition file specifies the boundary conditions while the hot start file stipulations the initial simulation start up conditions. These file are then compiled in an executable, which preprocess the information prior to the simulation. Then the model files are ran.

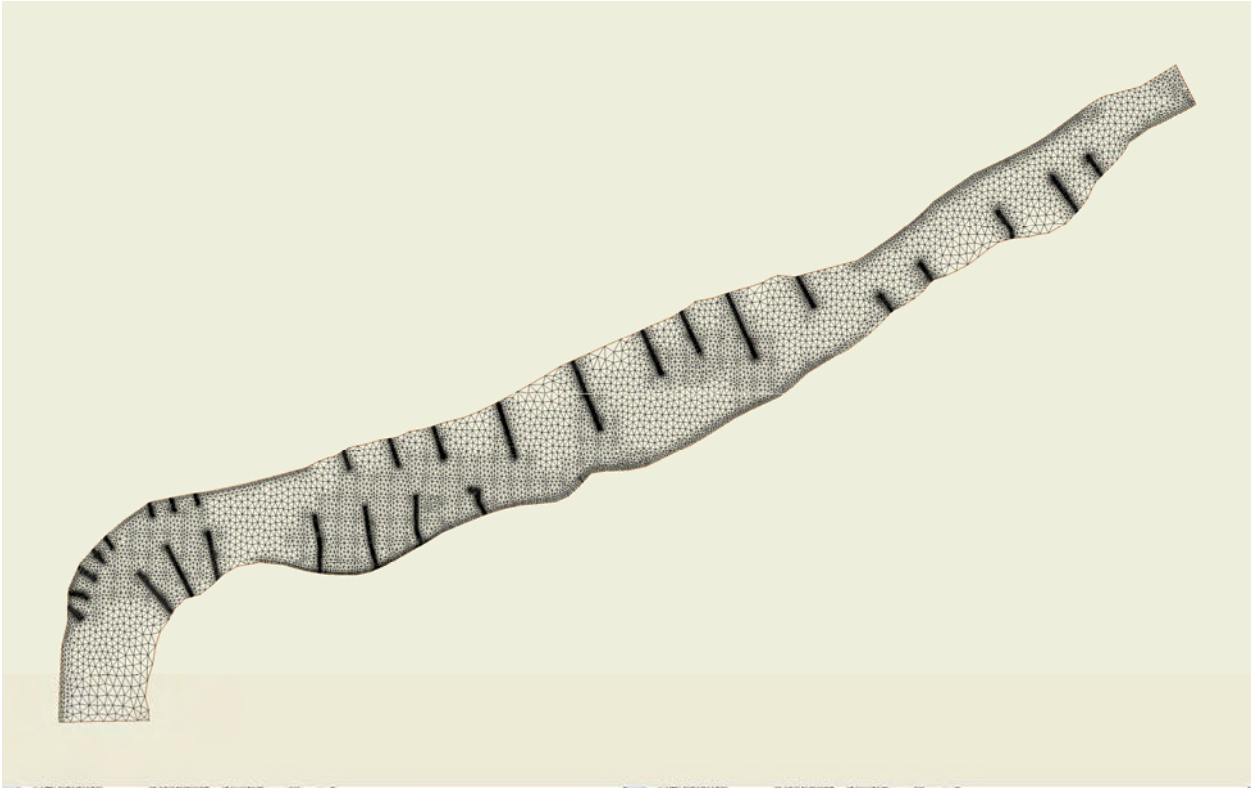

Figure 3 ADH mesh of Kate Aubrey.

Figure 3 shows the current configuration for the mesh, which consists of 12,908 nodes and 24,709 elements. In the domain there are 29 dikes represented. Although not ideal the mesh boundaries are located within in close proximity of the dike domain. The flow has been adjusted laterally to accommodate for lateral flow variation across the upstream boundary. For simplicity the model is computing an equilibrium transport volume for the incoming flux. This is a functionality in ADH that analysis the incoming sediment capacity of the flow and specifies it as such.

The selected hydrograph is the 1999 flow from the Hickman KY gauge; which, although is located several miles upstream is the closet gauge with a stage discharge rating curve. Discharge was not translated downstream to the domain since the analysis is only concerned with a demonstration. This implies lower than expected flows, i.e. lower sediment transport. Therefore, for future work it is advantageous to translate allowing for a more formal validation to current existing bathymetry data for future evaluation. The hydrograph is shown in Figure 4.

Figure 5 illustrates the bed displacement that occurs from the initial start of the run. Areas shaded in red are locations that deposition has occurred. Conversely, areas of blue are locations where erosion has taken place. As to be expected areas behind the dikes are depositing and the main channel where the thalweg is located is experiencing deposition. The file shown is the one that is implemented with the RAT.

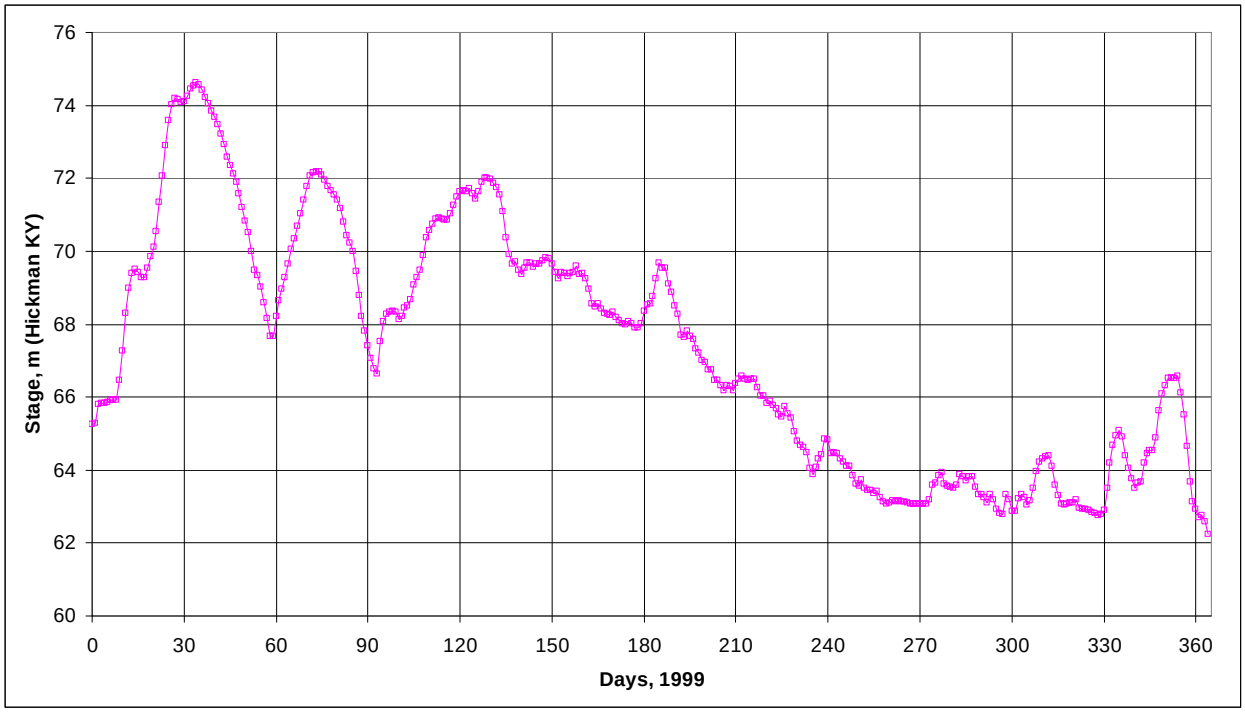

Figure 4 1999 Hydrograph simulated in ADH.

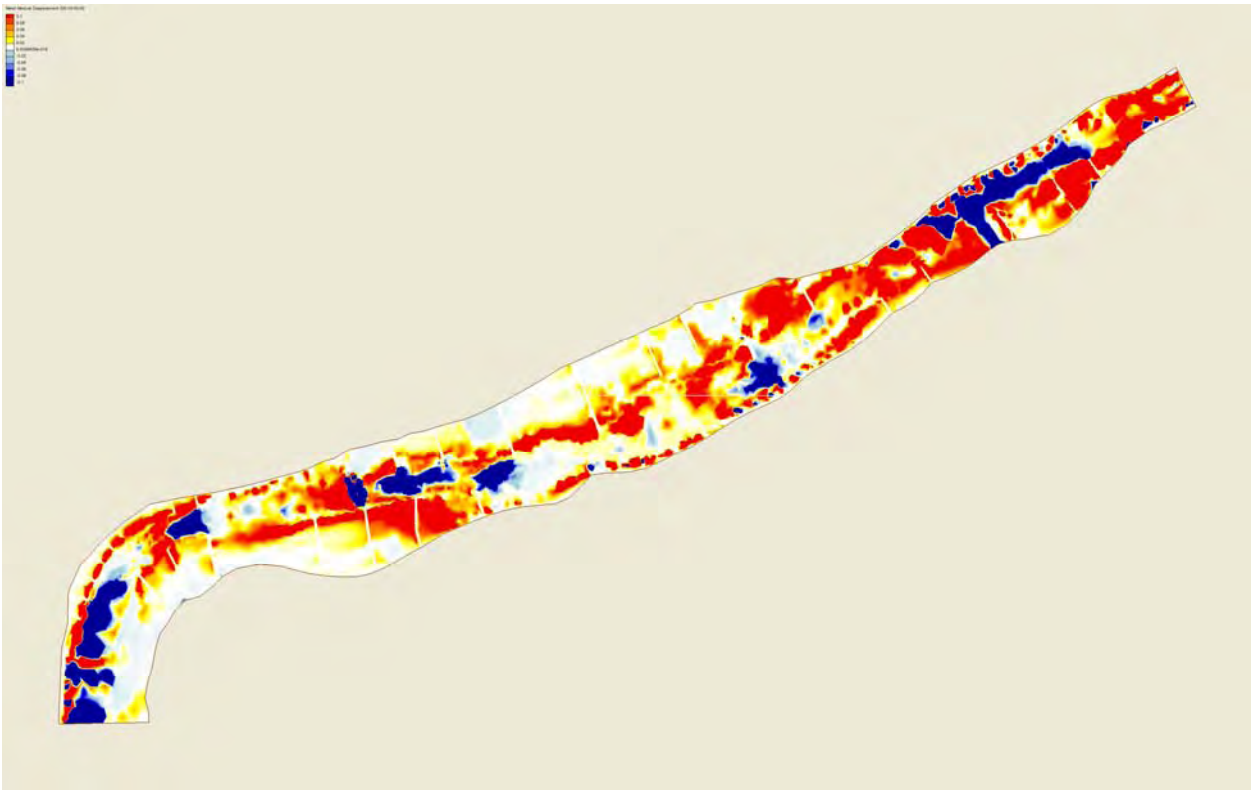

Figure 5 Bed displacements in ADH after 300 days of simulation.

RIVER ANALYSIS TOOL

The concept of the RAT was developed out of a need to do long term simulations such that geomorphic responses could be evaluated in a qualitative manor. Therefore, it provides a means for managers to evaluate river responses due to imposed changes. Note that the RAT is not a sediment transport model but is an indicator for sediment accumulation or erosional changes. The sediment transport portion of this analysis is preformed completely in the multi-dimensional model. This is achieved through the construction of bed rating curves; which, depict the depositional or erosional rate of each individual cell/node, in the multi-dimensional grid, and relate the rate of bed change back to the discharge forming a bed rating curve.

The ultimate goal of this tool is for the application of numerous numerical models, so that users are not limited to a specific model. Original RAT verification work has been done using the MIKE 21 model, and a more recent application has been done with ADH. Regardless the model the concept of the RAT is still the same. For simulation efficiency a series of steady state runs are complete all starting from a base or current system bathymetry. Steady state flows must cover the range of possible flows in the desired hydrograph so that the RAT can interpolate between flows not modeled in the numerical model. From the steady state runs, pertinent data required is the bed displacement or bed change; therefore, runs must be sufficient to cause a change in bed elevation to occur. Upon completion of the runs, which may include but not limited to anywhere from four to ten steady conditions, required input data associated is implemented in the RAT. Additional input is the desired hydrograph that the RAT is evaluating. From these inputs a long term geomorphic assessment is made by the RAT.

INFLUENCING FACTORS

For a non-tidal environment there are three influencing factors in river morphology that need addressing for the proper evaluation and prediction of future conditions. Similar factors were outlined by Savant (2008) for an estuary; however, here the factors vary due to the non-tidal component. First, the fundamental sediment dynamics that are naturally occurring behaviors that dictate the sediment transport. These can include but are not limited to sediment capacity, supply, physical properties, and flow dynamics. Next, the variations with respect to the hydrograph can affect the morphology. The occurrence and frequency of flows can rapidly vary the morphology of a system.

Factors associated with the sediment movement and transport behavior are evaluated in the multiple steady state runs conducted with ADH, or the multi-dimensional model. Here the fundamental sediment transport dynamics are solved and the complex non-linear functionality of the system is processed. It is important to have a verified code that can accurately model the system. Improper evaluation will be magnified in the RAT. Since rapidly varying changes can occur due to the hydrograph fluctuations it is important to run multiple hydrographs in the RAT to determine the associated morphing that occurs.

VALIDATION

Quantitative verification of this tool is virtually impossible, but qualitative verification is viable. Extreme complications arise in attempting to validate sediment models to historical events, much less multiple future predictions. By starting with the 1999 bathymetry and having the 1979 bathymetry two sets of validation is possible. Starting with the 1975 configuration, ADH can produce the required steady state runs to input into the RAT. Then the RAT can be run from 1975 to 1999 when the new dike configuration went in, and be validated based on depositional and erosional locations. This will proved a long enough simulation to determine if in its current state the RAT is capable of producing adequate results for longterm analysis. Furthermore, it will provide insight into the necessary changes to address some of the RAT's limitations. Additionally, 1999 configuration can be run forward to present conditions for yet another evaluation.

LIMITATIONS

With any forecasting tool it is important to understand the limitations and inabilities. Rat is no exception, and prior to use the user must understand these limitations before the tool can be appropriately applied. First, RAT is not a transport model and is only a morphological forecasting tool. A forecasting model, as with all models, will have an associated amount of error. Here there is a cumulative error effect with the conjunction of two models, since each has its own associated error which results in error magnification. Therefore, RAT should only be used in a qualitative approach to analysis holistic ramifications for river alterations. Next, the major issues with any forecasting tool are the boundary conditions. Varying both spatially and temporally boundary conditions are difficult to replicate for historic conditions much less for future unknown conditions for both in stream and the headwaters. Accommodations for future land use and flow variations from watershed alterations are required. This includes but not limited to BMPs, land-use-land-cover changes, watershed management changes, withdrawal and discharge permits, channel modifications, etc.

Additional limitations exist with unaccounted processes. Although the same magnitude flows occur both on the rising and falling limb of the hydrograph the sediment load can be drastically different. Systems that are supply limited are also not readily adjusted for. Both issues might be simply resolved through easily applied modifications. With all tools users should be aware of short falls.

CURRENT & FUTURE EVALUATION

Due to the rapid advancements with the ADH source code the legacy that ran the model for Tate and Berger (2006) is no longer available; therefore, the new version of the code is used to make the simulations. In particular, changes to the source code include transiting from the Exner routine to the more physics based advection, and diffusion processes for sediment transport. A considerable amount of time is applied to reconfigure the model such that it is compatible with the new source code. Currently, both the hydro and sediment portions of the model are operational and there is a one year simulation. Future work will include at least six steady state runs that capture all flows in that reach from 1975 through 2010. Once complete the required

input will be processed by the RAT and predictions will be calculated. Upon completion the above validation will be conducted.

ACKNOWLEDGMENTS

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