The Agricultural Ecosystem Services (AgES) Model: Overview and Application to the South Fork, IA USA Experimental Watershed (#455-817)

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USDA United States Department Of Agriculture Agricultural Research Service

Colorado State University

Study Overview

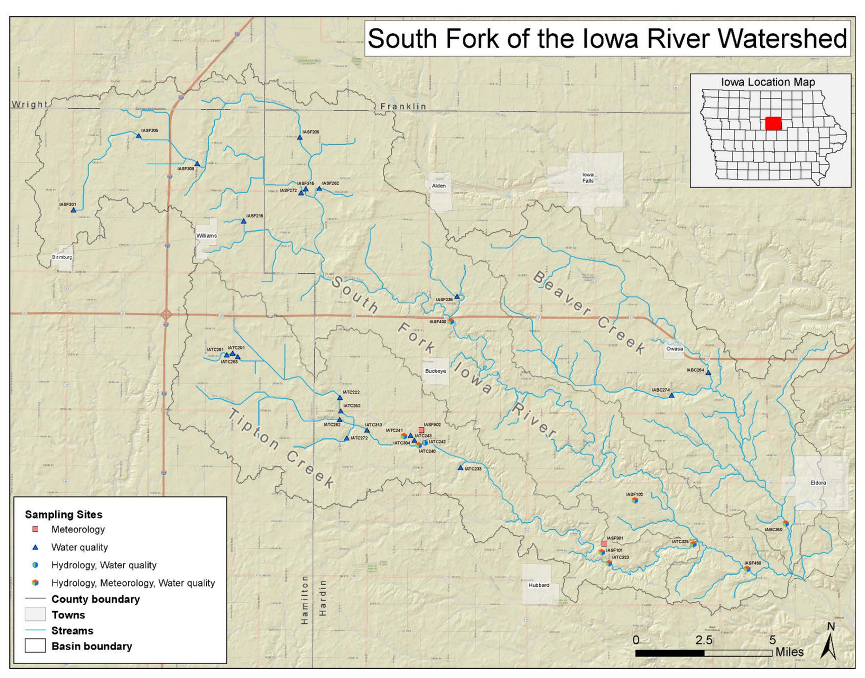
The specific objectives of this study were to: 1) implement hydrologic and water quality modeling components from the SWAT, AnnAGNPS, WEPP, and European J2K/J2K-SN models; 2) assemble a new component-based watershed scale model for fully distributed transfer of water and chemicals between land units and stream channels; and 3) evaluate the accuracy and applicability of the modular watershed model for estimating streamflow and nitrogen (N) transport. The watershed selected for model application was the South Fork Watershed (SFW) in central Iowa, USA. Results show that the Agricultural Ecosystem Services (AgES) model was able to reproduce the hydrological and N dynamics of the SFW with sufficient accuracy, and should serve as a foundation upon which to better quantify additional water quality indicators (e.g., P dynamics).

South Fork Watershed (SFW), Iowa USA

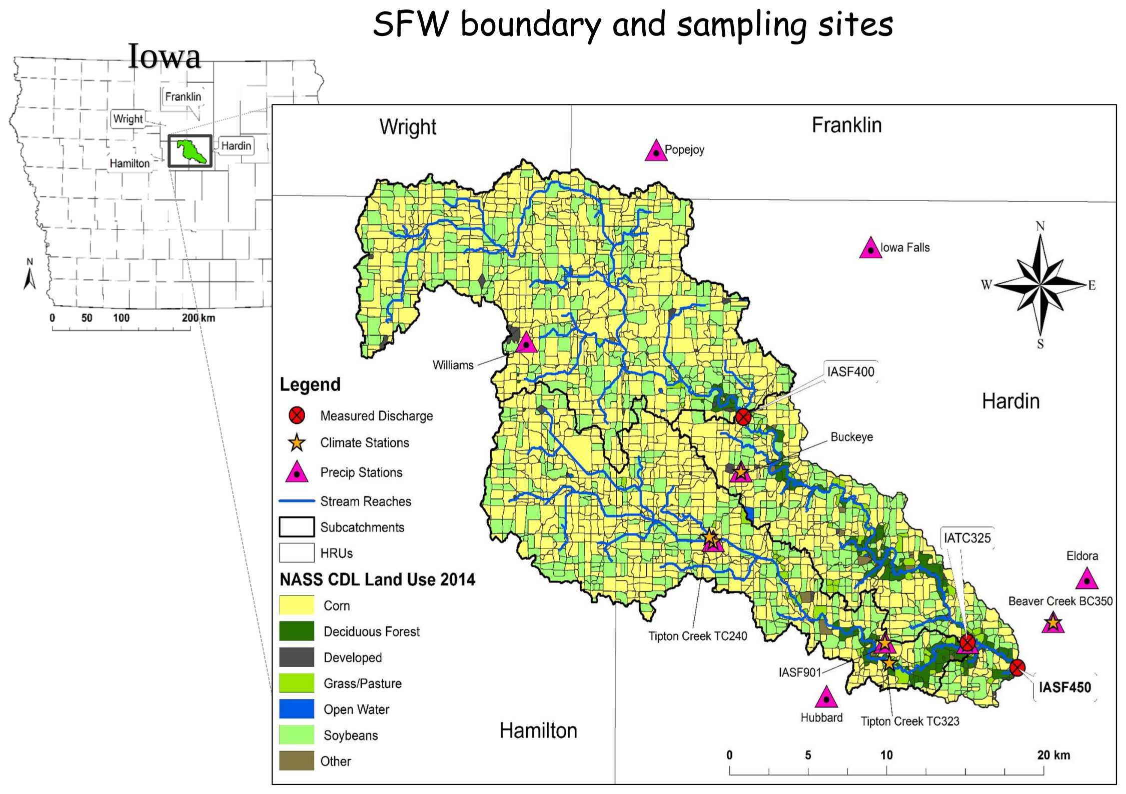
The South Fork Watershed (SFW) is located in central Iowa, USA. The SFW is approximately 581 km^2 (224 mi^2) and has center coordinates of 42° 25′ N and 93° 55′ W. Average annual precipitation in the SFW is 850 mm (33 in) and the average annual temperature is 10.5 °C (the average high and low temperature is 15.7 °C and 5.2 °C, respectively).

The watershed is more than 85% cropland, and the rest is mostly pasture or forest with smaller urban areas. Corn and soybeans are grown on 99% of the cropland areas. The SFW is dominated by pothole depressions and artificial subsurface tile drainage (needed to drain the hydric soils that cover nearly 75% of the watershed).

For watershed delineation, GIS layers (i.e., DEM with a resolution of 10m x 10m, soils, land use, and field land units) were partly reclassified and combined by overlay analysis using a custom "HRU Delineation Tool" in ArcGIS. The resulting polygons were further aggregated based on their attribute set to reduce the number of spatial entities. The HRU Delineation Tool also derived the topological routing scheme for the simulation of lateral runoff generation processes (which determines the multiple HRU-polygon and HRU-stream connections). The result of the HRU delineation is shown in the figure below. Based on the underlying field layer and additional post-processing, 3015 HRU polygons were delineated for the SFW with an average size of 19 hectares.



SFW boundary and sampling sites

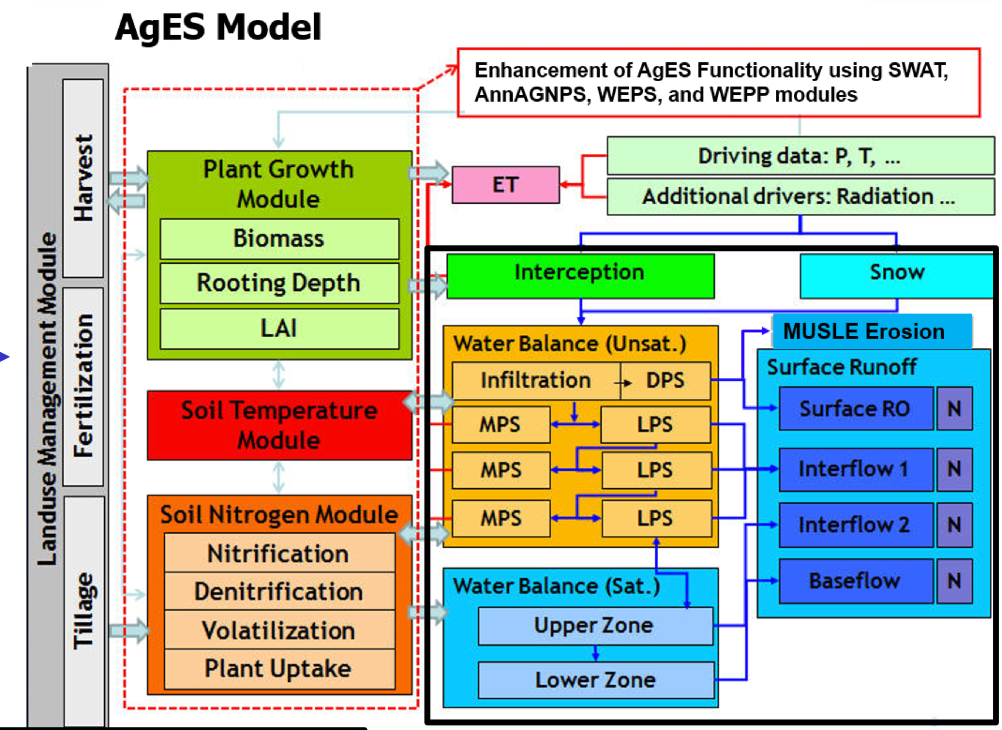


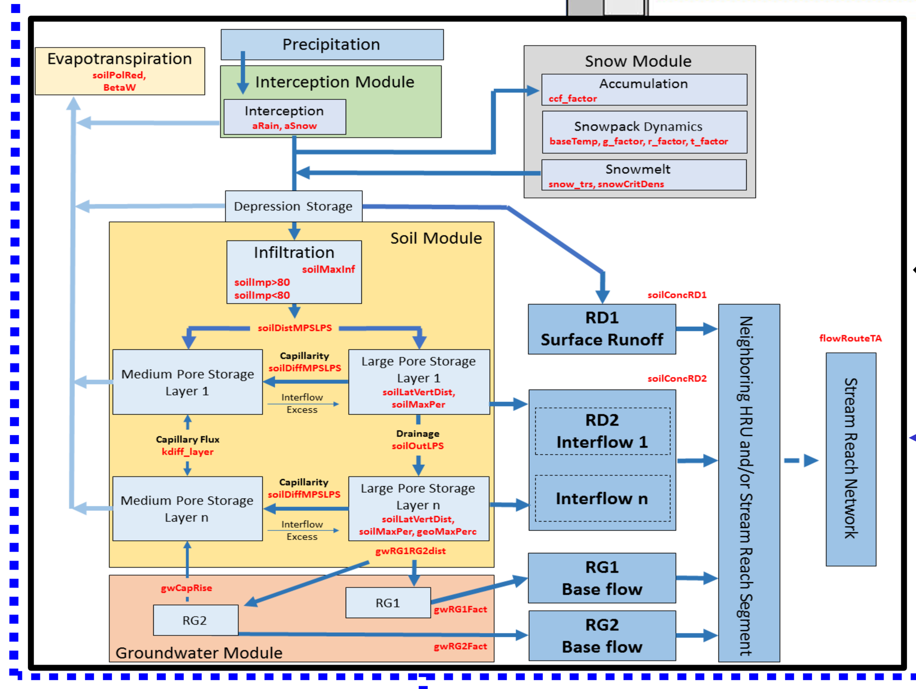
SFW AgES HRU delineation (3015 polygons)

Agricultural Ecosystem Services (AgES) Model

The AgES modeling system was used to simulate streamflow and N/sediment dynamics of the South Fork Watershed (SFW) in Iowa. AgES is a modular, spatially distributed modeling system which implements hydrological and water quality processes as encapsulated components under the Java Connection Framework (JCF). Runoff, N, and sediment loading are simulated in AgES at the Hydrologic Response Unit (HRU) level with subsequent calculation of runoff concentration and N/sediment transport processes (through a lateral routing scheme) and water/chemical routing in the channel network. AgES employs a topologically connected (HRU-to-HRU, HRU-to-stream, and HRU-to-HRU/stream) pattern of multiple land units with similar data features. The generation of different runoff components [surface runoff (RD1), unsaturated interflow (RD2), saturated interflow from the underlying hydrogeological unit (RG1), and saturated baseflow (RG2)] is simulated for each HRU. Also simulated are soil N processes (e.g., nitrification, denitrification, volatilization, plant uptake), sediment transport processes, plant growth processes, soil temperature, and various management processes. Watershed-wide input data sets are used as driving parameters, together with the physiogeographic parameters of each HRU (derived from DEM, soil, land use, and hydrogeology GIS data layers).

AgES Model Conceptual Diagram

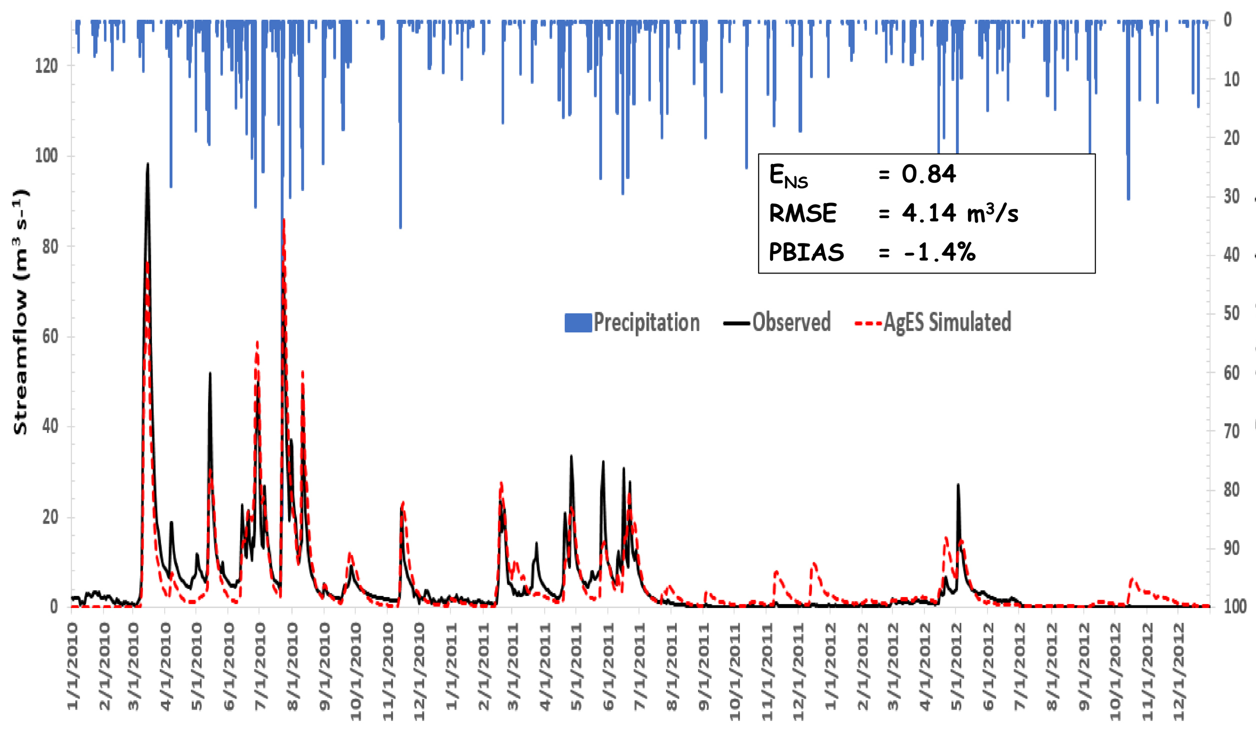




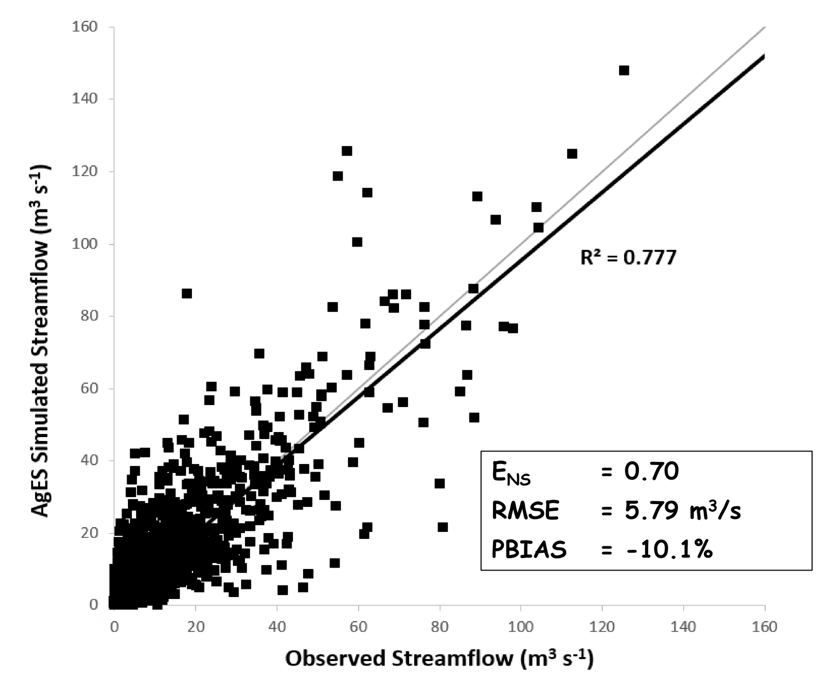
AgES Soil WaterModule

AgES SFW Streamflow, NO_3-N, and Sediment Simulation Results

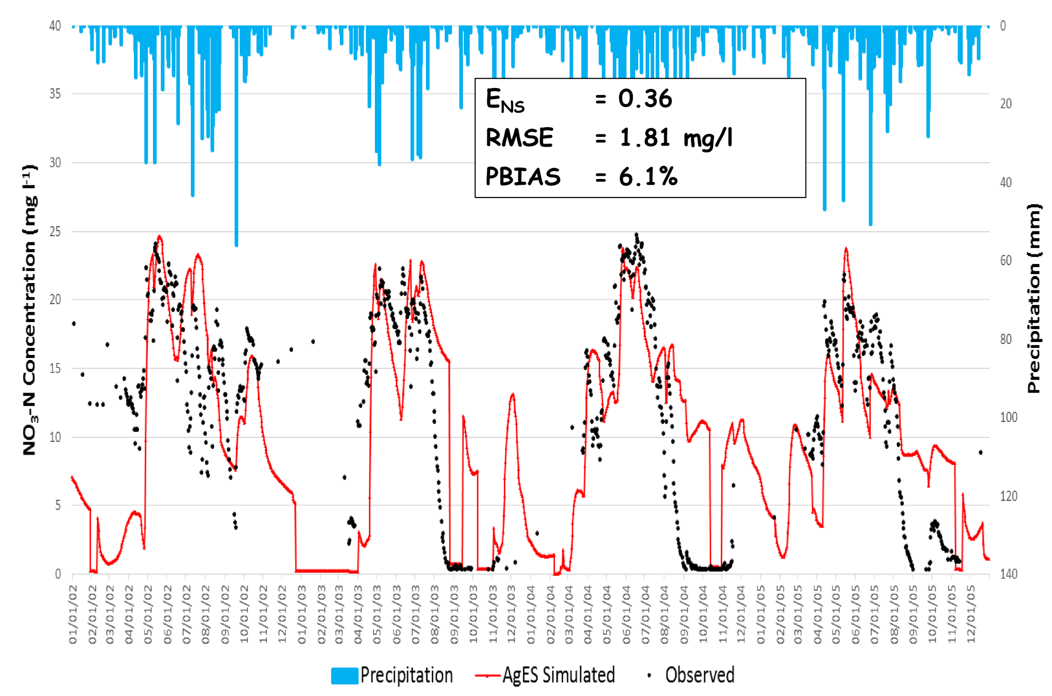
The AgES calibration and evaluation periods in this study were 2010-2012 and 2001-2009, respectively for streamflow and varied for NO_3-N concentration and sediment load. Daily measured streamflow, NO_3-N concentration, and sediment loading data at USGS gauge IASF450 (the SFW outlet) were used for calibration and evaluation. The calibration procedure was based on the Shuffled Evolution Complex (SCE) algorithm and used both single and multi-objective functions. Nash-Sutcliffe Efficiency coefficient (E_{NS}), RMSE, and percent bias (PBIAS) statistical evaluation coefficients were used to evaluate the overall correspondence of simulated output to measured values.



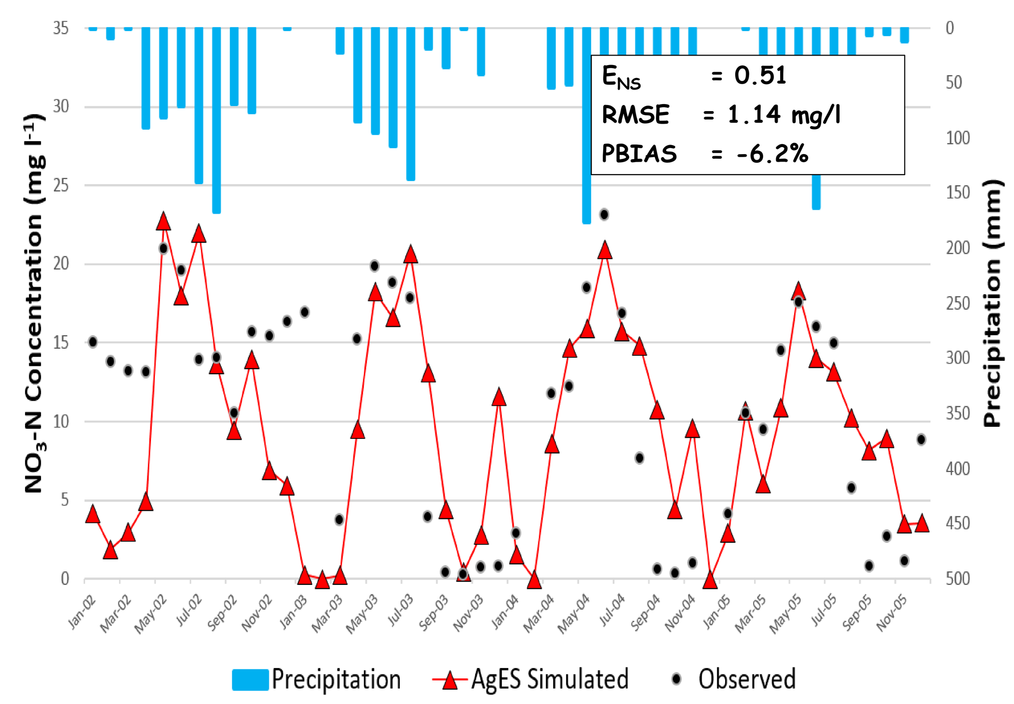
Daily AgES simulated and observed streamflow (m^3 s^{-1}) at SFW gauge IASF450 (calibration period – 1 Jan 2010 to 31 Dec 2012)



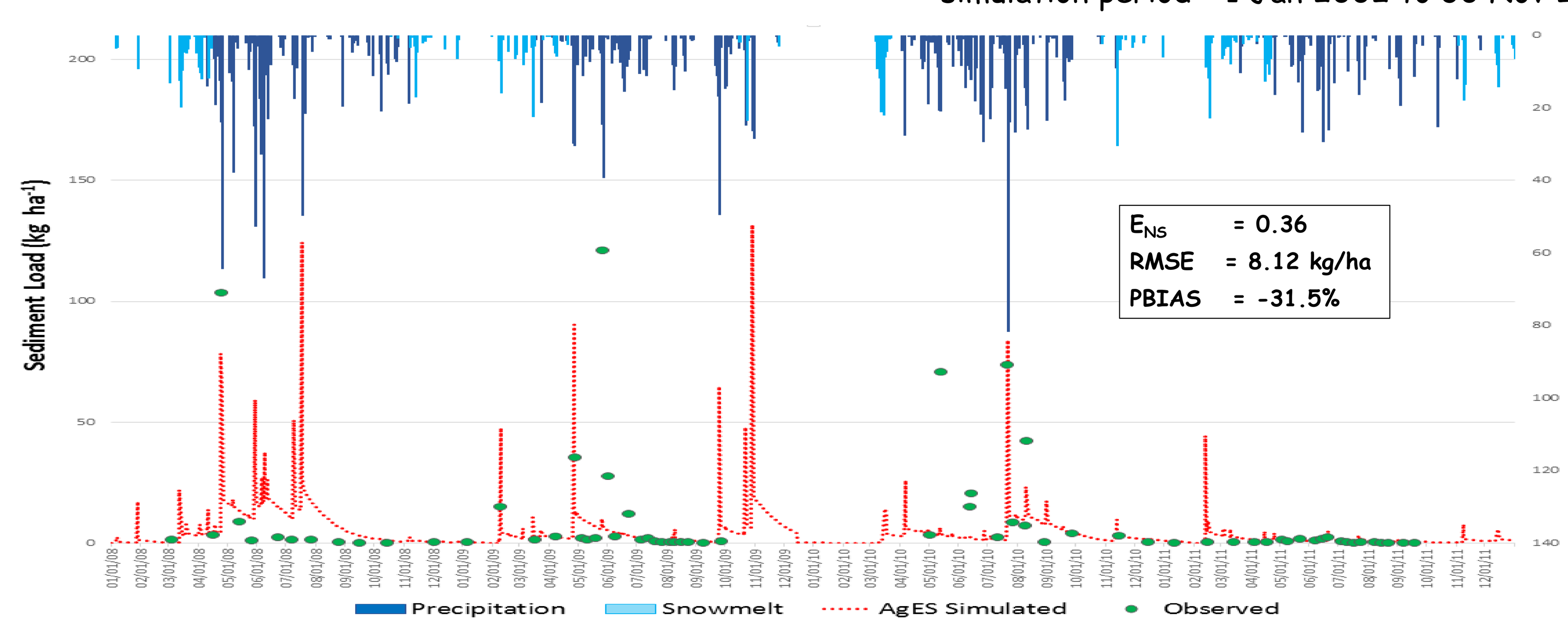
Daily AgES simulated vs. observed streamflow (m^3 s^{-1}) at SFW gauge IASF450 (entire simulation period – 1 Jan 2001 to 31 Dec 2012)



Daily AgES simulated and observed NO_3-N concentration (mg l^{-1}) at SFW gauge IASF450 (entire simulation period – 1 Jan 2002 to 30 Nov 2005)

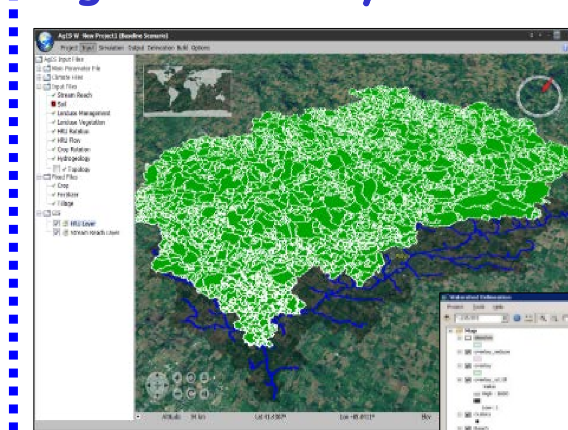


Monthly AgES simulated and observed NO_3-N concentration (mg l^{-1}) at SFW gauge IASF450 (entire simulation period – 1 Jan 2002 to 30 Nov 2005)

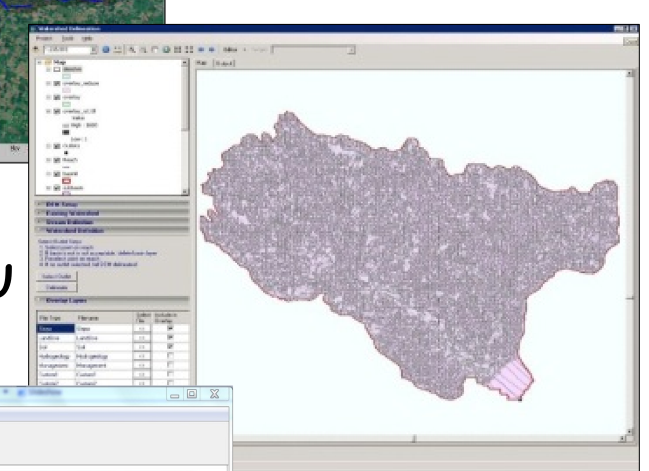


Daily AgES simulated and observed sediment load (kg ha^{-1}) at SFW gauge IASF450 (entire simulation period – 1 Jan 2008 to 31 Dec 2011)

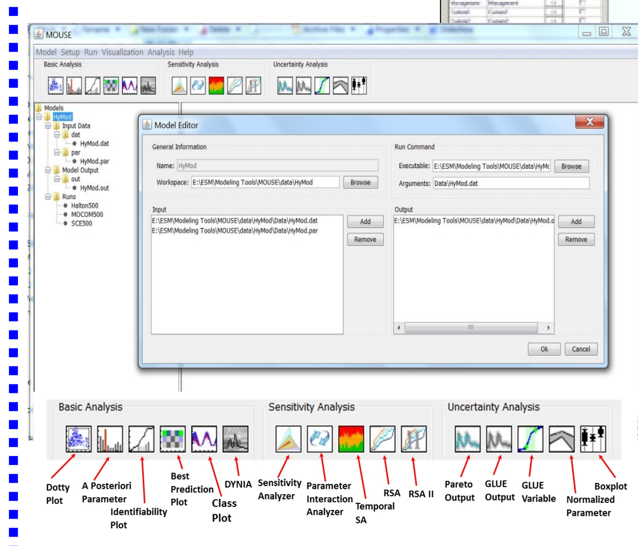
AgES Auxiliary Tools



AgES GUI (NASA WorldWind™)



ArcGIS 10.4 HRU Delineation Tool



Model Optimization, Uncertainty, and SEnsitivity Analysis (MOUSE) open-source, Java-based toolbox

Summary and Conclusions

Considering that AgES was applied with only minor calibration, results indicate that the model reproduced SFW streamflow very well and NO_3-N concentration reasonably well. However, sediment loading in the SFW was somewhat harder to predict and may be due to the fact that AgES uses only daily (rather than breakpoint) precipitation data. Additional model enhancement (e.g., addition of Green-Ampt infiltration and water table components) should provide a solid foundation on which to improve AgES in order to better quantify water quantity and quality at the watershed scale. In particular, the topological routing scheme employed by AgES is considerably more robust than the quasi-distributed routing schemes used by SWAT and other watershed-scale natural resource models. With a fully distributed routing concept, higher spatial resolution in combination with the lateral transfer of water and chemicals between HRUs and stream reaches will hopefully result in improved H/WQ modeling for mixed-use watersheds such as the SFW.

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