Assessment of NASA's physiographic and meteorological datasets as input to HSPF and SWAT hydrological models

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Abstract

This paper documents the use of simulated Moderate Resolution Imaging Spectroradiometer land use/land cover (MODIS-LULC), NASA-LIS generated precipitation and evapo-transpiration (ET), and Shuttle Radar Topography Mission (SRTM) datasets (in conjunction with standard land use, topographical and meteorological datasets) as input to hydrological models routinely used by the watershed hydrology modeling community. The study is focused in coastal watersheds in the Mississippi Gulf Coast although one of the test cases focuses in an inland watershed located in northeastern State of Mississippi, USA. The decision support tools (DSTs) into which the NASA datasets were assimilated were the Soil Water & Assessment Tool (SWAT) and the Hydrological Simulation Program FORTRAN (HSPF). These DSTs are endorsed by several US government agencies (EPA, FEMA, USGS) for water resources management strategies. These models use physiographic and meteorological data extensively. Precipitation gages and USGS gage stations in the region were used to calibrate several HSPF and SWAT model applications. Land use and topographical datasets were swapped to assess model output sensitivities. NASA-LIS meteorological data were introduced in the calibrated model applications for simulation of watershed hydrology for a time period in which no weather data were available (1997-2006). The performance of the NASA datasets in the context of hydrological modeling was assessed through comparison of measured and model-simulated hydrographs. Overall, NASA datasets were as useful as standard land use, topographical , and meteorological datasets. Moreover, NASA datasets were used for performing analyses that the standard datasets could not made possible, e.g., introduction of land use dynamics into hydrological simulations.

1. Introduction

Hydrologic and water quality modeling, at the watershed scale, involves managing large volumes of data. The management of these large data volumes usually requires the linking of Geographical Information Systems (GIS) and hydrological models. GIS programs are used for extracting and summarizing geographical information from private or public-domain geo-databases for the purposes of watershed delineation, land use characterization, geographical positioning of hydro-chemical point sources, etc. Hydrological models receive formatted input data from the GIS programs and require additional meteorological and water quality data for simulation of hydrology and water quality in the watershed under study. Partially-existent or non-existent physiographic and meteorological data (precipitation, land use, topography, evapo-transpiration, etc.) oftentimes limit the application of hydrological models to certain areas in the US or the world.

NASA topographical and land use products have global coverage and frequent collection times; as such, they are excellent candidates for replacing or complementing datasets that are currently used by the watershed hydrology community. NASA Land Information System (LIS) models are able to generate time-series of meteorological and other forcing data for regions around the globe. Table 1 shows details on standard physiographic datasets currently used by the watershed hydrology modeling community in the USA.

Table 1. Datasets currently used watershed hydrology modeling in the USA

	Dataset	**Provider**	**Limitations**
Topography	DEM: 300 m resolution, NED: 30 m resolution	USGS (EPA, 2010a)	Depending on the size of the watershed under study DEM could result a coarse approximation to actual relief
Land use, land cover	GIRAS: 400 m resolution, NLCD: 30 m resolution	USGS (EPA, 2010b; EPA, 2010c; USGS, 2005)	Both datasets are outdated. The most current dataset is NLCD-2001, based in land use information collected during the 1990's
Precipitation	Gage station records at hourly, daily frequencies	NCDC (NOAA, 2010)	Several stations have incomplete time-series

NASA products match some of the current datasets specifications and offer updated physiographic and continuous meteorological time-series as shown in Table 2. The potential of NASA products for their use in watershed hydrology modeling is evident.

Table 2. NASA datasets with similar quality to standard topographical, land use and meteorological datasets.

Satellite/Model	Sensor	System Operator	Product
Shuttle Radar Topography Mission	RADAR: two radar antennas located in the shuttle's payload bay, and the other on the end of a 60-meter mast	NASA, NGA	SRTM 30-meter resolution digital elevation model within USA, 90-meter resolution for the rest of the world (NASA, 2006)
TERRA/AQUA	Moderate Resolution Spectroradiometer (MODIS)	NASA	MODIS 12Q1 land use land cover, 1000 m resolution (NASA, 2009)
LIS		NASA GODDARD	Precipitation and Evapotranspiration time-series (Kumar et al. , 2006;, Peters-Lidard et al.., 2007)

Among the wide variety of hydrological models available for watershed modeling, two of the most popular models in the USA are the Hydrological Simulation Program Fortran (HSPF, and the Soil Water & Assessment Tool (SWAT).

HSPF is a public-domain computer program that models and simulates watershed hydrology and water quality using hourly or daily precipitation and other meteorological/water-quality time-series, parameterized topographical and land use information, and measured stream flow and water quality. It simulates the hydrological cycle (interception, run-off, evaporation, etc.) conceptualizing the watershed in lumped-parameter pervious or impervious unit areas discharging to river reaches or reservoirs (Bicknell et al. 2001). The result of a simulation is a time history of the runoff flow rate, sediment load, and nutrient and pesticide concentrations, along with a time history of water quantity and quality at any point in a watershed (UCDAVIS, 2010a). Programs available separately (WDMUtil and GenScn) support data preprocessing and post-processing for statistical and graphical analysis of data saved to a Watershed Data Management (WDM) file. Experience with HSPF indicates that regional precipitation, topography, and land use data inputs drive the simulation of hydrological processes in watersheds. However, lack of meteorological monitoring stations, coarse spatial resolutions of land use and land cover datasets, as well as outdated coverage usually constrain watershed hydrology modeling efforts.

SWAT is a river basin scale model developed to quantify the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (USDA-ARS, 2010). SWAT is an effective tool for assessing water resource and non-point pollution problems for a wide range of scales and environmental conditions across the globe. SWAT is being used worldwide for Total Maximum Daily Load analyses (TMDLs), conservation practices assessment, macro-scale watersheds assessments (Gassman et al., 2007). The main components of SWAT include weather, surface runoff, return flow, percolation, evapo-transpiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer (UCDAVIS, 2010b). Utilizing SWAT to provide a distributed model (as opposed to the lumped-parameter approach employed by HSPF) will enable a rigorous comparison of the two models (HSPF vs. SWAT) within a common experimental unit (same geographic and temporal range) using the same input data products.

This paper presents a review of several studies (Alarcon & O’Hara, 2010; Diaz et al., 2008, Alarcon & O’Hara, 2006) undertaken at the Geosystems Research Institute, Mississippi State University, assessing the usefulness of NASA’s Moderate Resolution Imaging Spectroradiometer Land use/land cover data (MODIS 12 Q1), Shuttle Radar Topography Mission (SRTM) topographical datasets, and NASA’s Land Information Systems (LIS) precipitation and evapo-transpiration time-series, for hydrological modeling and simulation. The paper also presents unpublished results on the assimilation of historical MODIS land use and NASA-LIS spatially-distributed precipitation time-series for hydrological modeling. The widely known Hydrological Simulation Program FORTRAN (HSPF) and Soil Water & Assessment Tool (SWAT) hydrological models are used for estimating hydrographs in three watersheds located in the State of Mississippi, USA. Calibration and validation of the base-case hydrological model applications generated for this study are performed using precipitation and stream flow gage station data from public data repositories from USGS and NCDC.

2. Review of preliminary studies

The initial assessment of the utility of NASA datasets in the context of hydrological modeling was organized in a series of experiments. In those preliminary experiments, the MODIS and/or SRTM datasets were compared to standard datasets and were evaluated in their performance for either capturing the parameterized topographical/land-use characteristics used by the hydrological models, or by inputting the parameterized information extracted from the NASA datasets in calibrated hydrological models (set up with standard topographical and land use datasets). The results of the experiments are summarized in several papers: Alarcon & O’Hara, 2010; Diaz et al., 2008, Alarcon & O’Hara, 2006. A review of those publications is presented in the next subsections.

2.1 Topography experiment

Watershed delineation is the hydrologic division of a watershed into sub-watersheds that are relatively homogeneous. This homogeneity is determined taking into account land use, topography and other criteria and information. Although land use and other factors play an important role within the process of delineating a watershed, topography is used as the primary reference. With the widespread availability of digital elevation databases, watershed delineation has been automated in many GIS/hydrologic software. This automation, however, has made delineation very dependent on the quality of the digital elevation data. DEM grid size, scale and resolution affect substantially watershed delineation. This is more evident in coastal areas where elevation differences are small and sub-basin areas tend to be large. In this exploratory experiment, Interferometric Synthetic Aperture Radar (IFSAR) and Shuttle Radar Topography Mission (SRTM) data were used to delineate selected regions of the Saint Louis Bay watershed (Mississippi). In addition to these two digital elevation databases, NED and USGS digital elevation models were also used for delineation.

This experiment (further detailed in Alarcon and O'Hara, 2006) compared the performance of the Shuttle Radar Topography Mission (SRTM) elevation datasets against standard topographical datasets (USGS-DEM, NED, and IFSAR) in capturing topographical parameters critical for hydrological modeling, as well as the SRTM use for watershed delineation. The study area was the Jourdan River catchment, located in the Saint Louis Bay watershed (Mississippi Gulf Coast).

Figure 1 shows final delineation results for each of the elevation datasets used in this study. The delineation experiment provides similar distribution of sub-basins. However, the demarcation of sub-basin boundaries is different in each case. The most convoluted sub-basin perimeters correspond to delineations made using the IFSAR dataset (Figure 1B). In addition to a more tortuous perimeter, the IFSAR topography produces isolated interior areas that do not belong to any sub-basin. This dataset also required more processing and memory requirements than the other three datasets. On the other hand, SRTM, NED and USGS-DEM produce smooth and continuous demarcation of sub-basins.

In terms of parameterized topographical information from the datasets used in this experiment, Figure 2 shows that SRTM provides basic topographical parameters similar to the standard datasets.

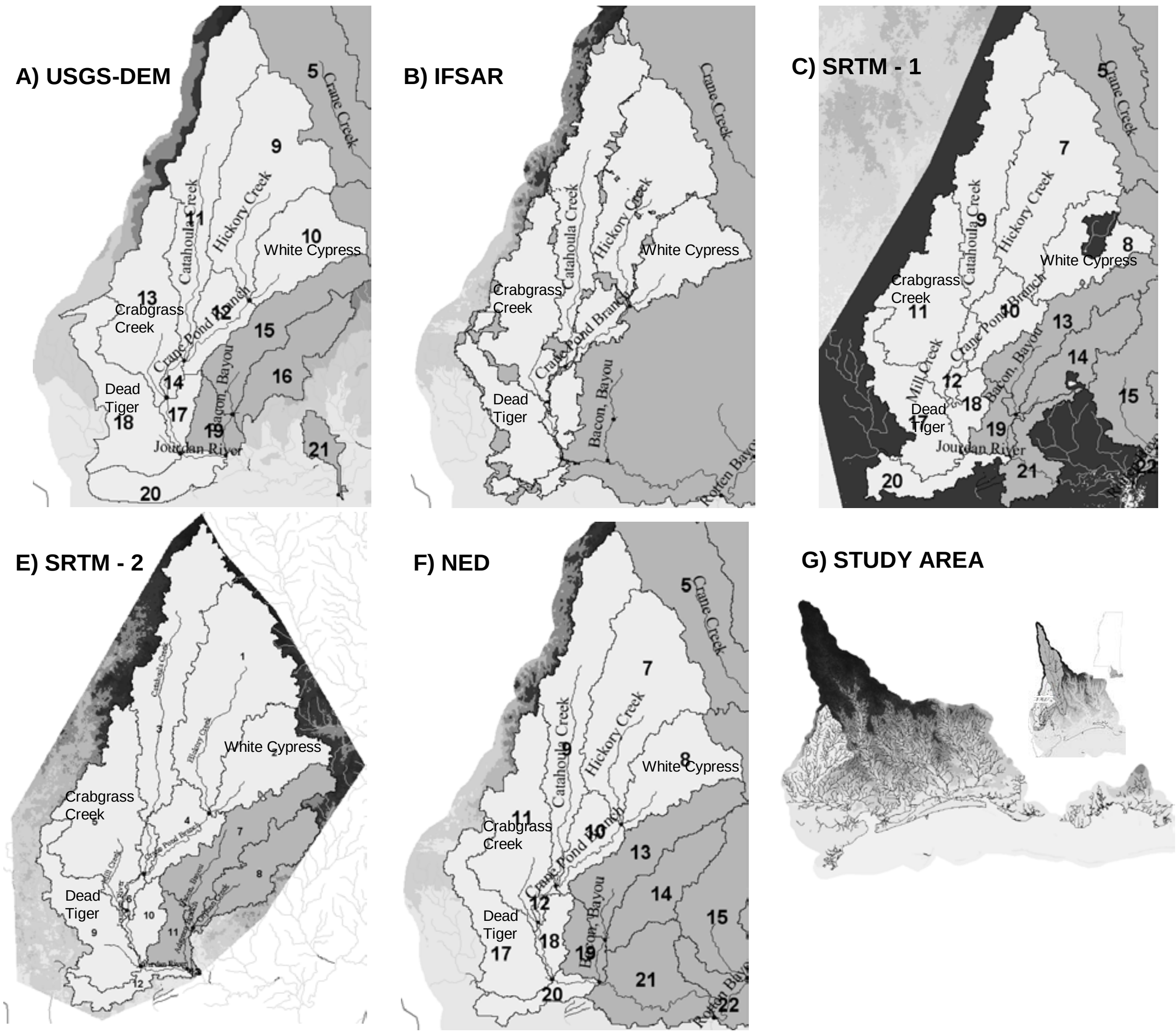


Figure 4. Watershed delineation using several elevation datasets (adapted from Alarcon & O'Hara, 2006).

SRTM, NED and USGS-DEM produced equivalent, smooth and continuous demarcation of sub-basins. Therefore, the experiment determined that the use of SRTM provides equivalent delineation results and topographical parameterized information.

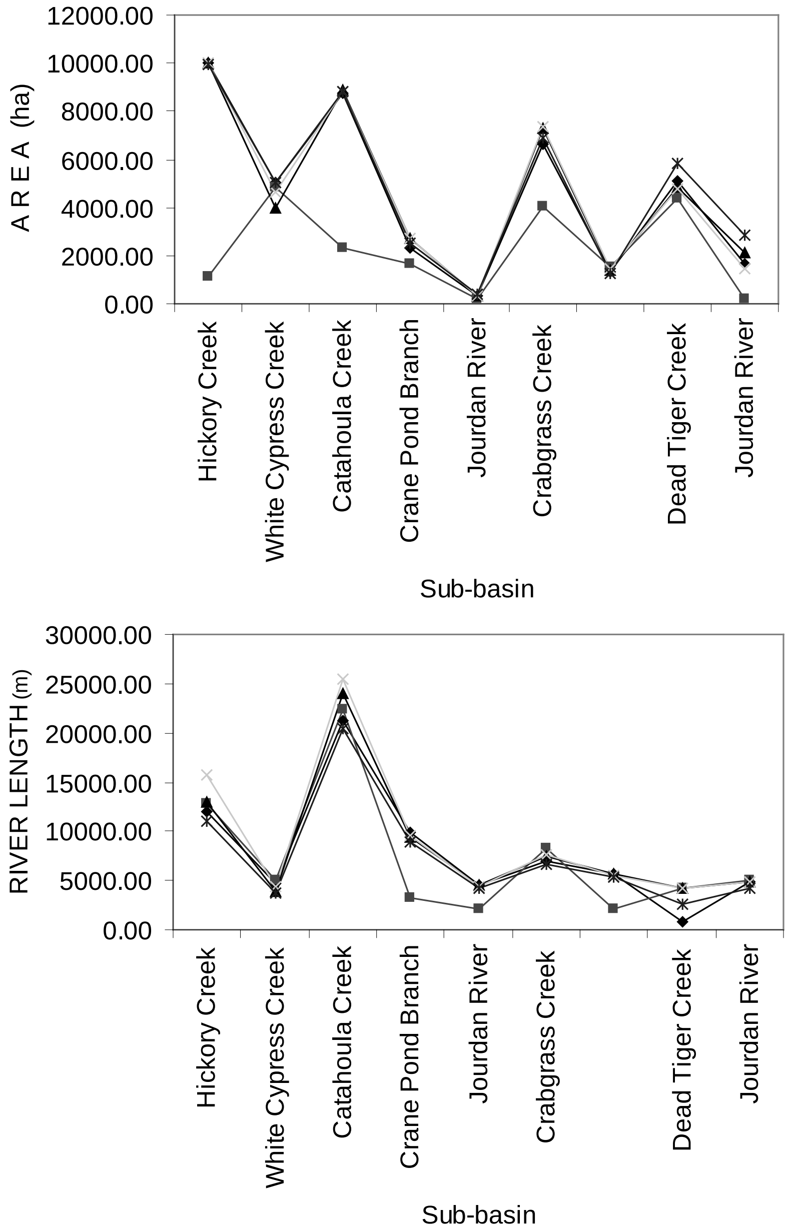


Figure 2. Topographical parameters extracted from several different topographical datasets (adapted from Alarcon & O'Hara, 2006).

3.2 Land use experiment

This experiment explored the impact of land-use data quality in the simulation of watershed processes at hill slope scale and at the watershed outlet of the Luxapallila Creek basin, located in northern Alabama and Mississippi (see Figure 3). The outlet of the watershed is shown in Figure 1 right on the urban concentration land use category (black pixels at the southeastern tip of the watershed), and is located near USGS Station 02443500. Simulated values of flow and sediments were obtained after swapping three land use datasets (NLCD, USGS-GIRAS, and MODIS). The changes in simulated values were analyzed and compared. The HSPF hydrological model was used to perform the hydrological estimations.

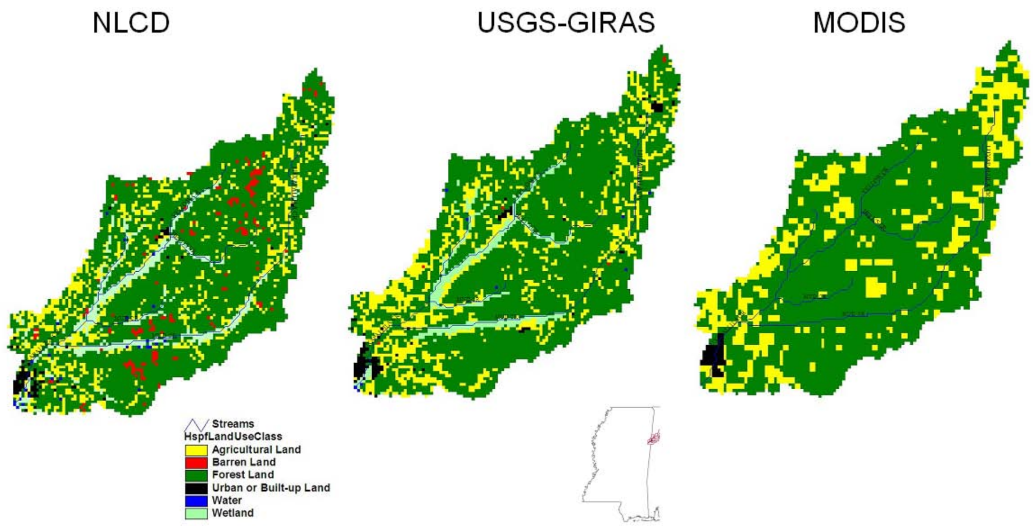


Figure 3. HSPF land use maps from NLCD, USGS-GIRAS, and MODIS datasets and corresponding to Luxapallila watershed (adapted from Diaz et al., 2008). USGS-GIRAS and MODIS land use maps show greater presence of agricultural areas.

Daily stream flow data, recorded at USGS gauging station (02443500) at the outlet of the watershed, was compared to HSPF-simulated stream flow at the same location. The hydrologic calibration was performed for the period January 1, 1985 to September 30, 2003.

Figure 4 shows scatter plots for simulated stream flow, and total amount of simulated sediment fraction. The charts compare HSPF simulated output using GIRAS versus NLCD and MODIS datasets. Simulated stream flow did not show a substantial change when land use datasets were swapped. Estimated sediment fraction values using the MODIS dataset are shown to be higher than those values estimated using GIRAS, while NLCD-simulated sediment fraction values tend to be smaller than GIRAS-estimated values. These results show that land use datasets that identify more presence of agricultural areas (MODIS and GIRAS) produced HSPF-estimations of sediment fraction values bigger than the NLCD land use dataset (that identifies less presence of agricultural areas).

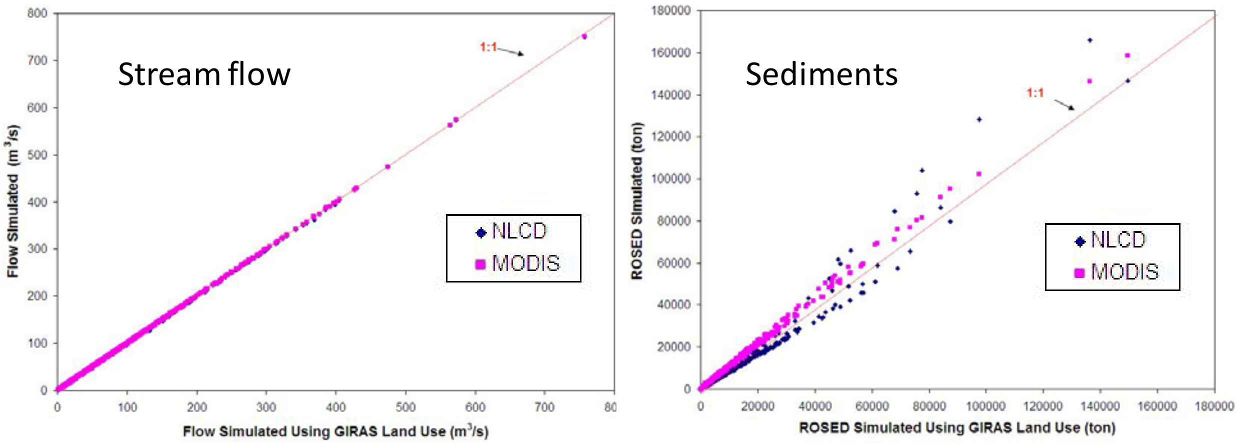


Figure 4. Scatter plot of simulated flow using GIRAS versus NLCD and MODIS (left), and total amount of sediment fraction contained in outflow simulated using GIRAS versus NLCD and MODIS (right) (adapted from Diaz et al., 2008) .

3.3 Land use and topography combined experiment

This experiment (further detailed in Alarcon and O'Hara, 2010) explored the effects of swapping several topographical and land use datasets of different spatial resolution and scale in hydrological estimations of stream flow.

A factorial design with several different land use and topography datasets was implemented (see Table 3). Twelve scenarios of topographical and land use datasets combination cases were generated for input into HSPF models of two watersheds.

Table 3. Factorial experiment combining topographical and land use datasets

COMBINED EXPERIMENT	LAND USE DATASETS		
TOPOGRAPHICAL DATASETS	MODIS (1000 m)	GIRAS (900 m)	NLCD (30 m)
DEM (300 m)	DEM\MODIS	DEM\GIRAS	DEM\NLCD
NED (30 m)	NED\MODIS	NED\GIRAS	NED\NLCD
SRTM (30 m)	SRTM\MODIS	SRTM\GIRAS	SRTM\NLCD
IFSAR (5 m)	IFSAR\MODIS	IFSAR\GIRAS	IFSAR\NLCD

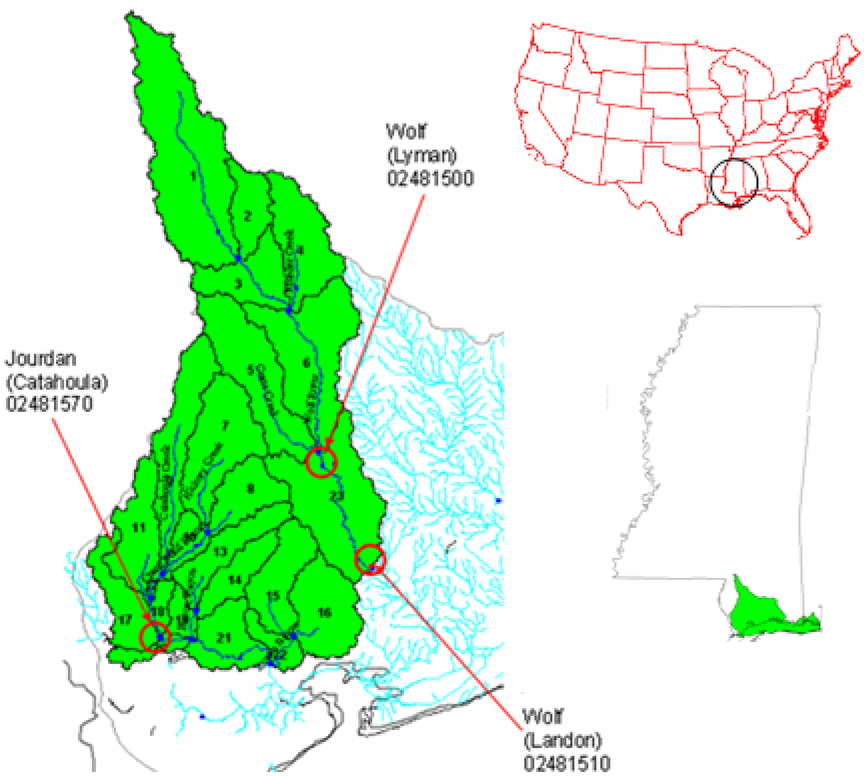
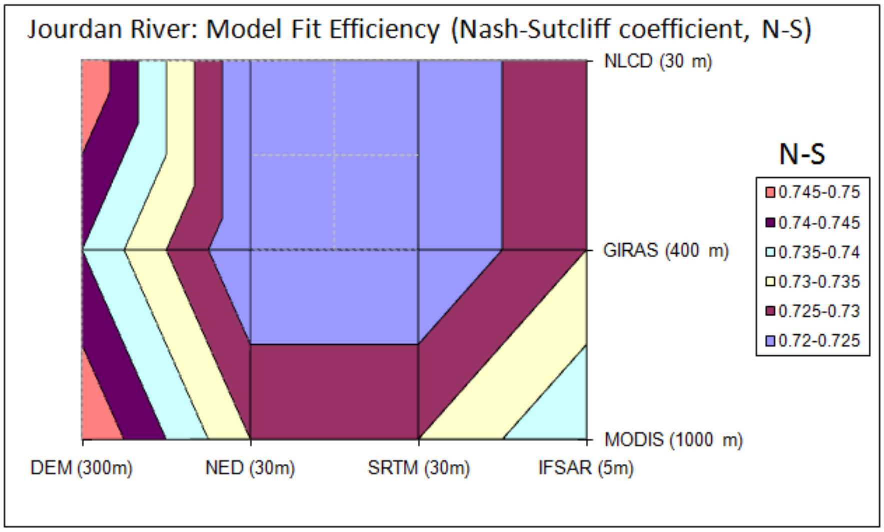


Figure 5. Watersheds included in the land use and topography combined experiment. USGS stream flow gage stations (at Catahoula, Lyman, and Landon) were used for calibration and validation of the HSPF model applications for Jourdan River and Wolf River watersheds.

The land use data used in this experiment corresponded to GIRAS (400 m resolution), National Land Cover Dataset (NLCD, 30 m res.), and MODIS MOD12Q1 dataset (1000 m resolution). Topographical data from the following sources were used: IFSAR (5-m horizontal res.), NASA's SRTM DTED Level 2 (30-m horizontal res.), National Elevation Data (NED) (30-m horizontal res.), and USGS DEM (300-m horizontal res.). All datasets were geo-processed clipped, re-projected, and re-classified to meet the needs of the HSPF model.

Two main river catchments in Saint Louis Bay watershed at the Mississippi Gulf Coast were the focus of this experiment (Figure 5): the Jourdan River catchment, draining approximately 88220 ha and being the largest contributor of flow to the St. Louis Bay (average stream flow of 24.5 m^3/s); and the Wolf River flows into St. Louis Bay from the east. The Wolf River catchment drains slightly more than 98350 ha with an average stream flow of 20.1 m^3/s.

After calibrating and validating the HSPF applications to Jourdan and Wolf watersheds using the finest resolution datasets (NED and NLCD combined), HSPF was used to simulate stream flow hydrographs for each of the 12 combinations shown in Table 3. Those simulated stream flow hydrographs were compared to measured stream flow and the following best-fit coefficients were assessed: coefficient of determination (r^2); Nash-Sutcliff model fit efficiency (NS). Figure 6 shows final results for Jourdan River and Wolf River watersheds.



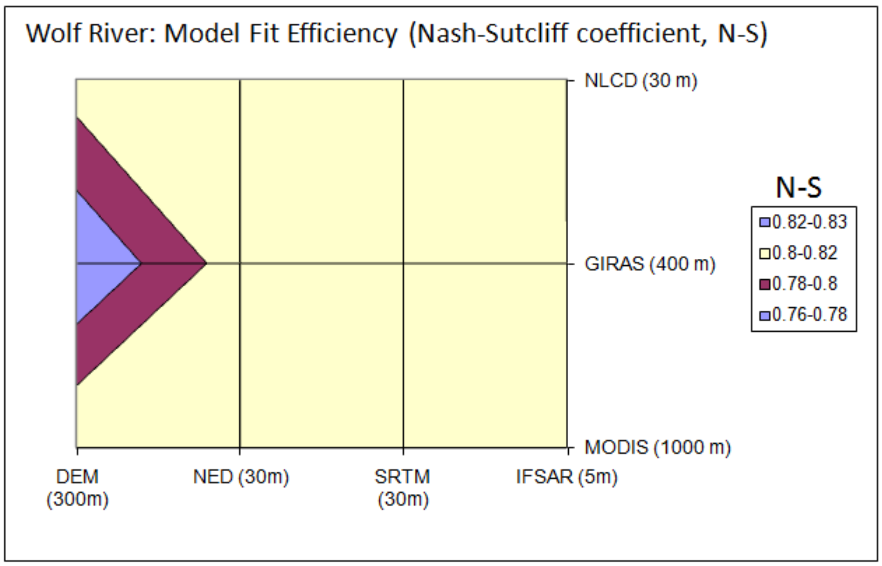


Figure 6. Final results of the land use and topography combined experiment. Notice that the combination of SRTM and MODIS provide model fit efficiencies (assessed by the Nash Sutcliff coefficient, N-S) greater than 0.725.

The combination of moderate resolution topographical datasets (such as SRTM, 30 m) and low resolution land use datasets (such as MODIS, 1000 m) produced statistical fits between simulated and measured stream flow hydrographs comparable to the standard datasets. Model fit coefficients (Nash-Sutcliff, NS) for the MODIS-SRTM combination range between 0.725 and 0.81 (perfect fit is 1.00).

3 Additional experiments using NASA datasets for hydrological modeling

To further assess the adequacy of NASA datasets for hydrological modeling, the land use and topography NASA products were further tested in non-traditional hydrological modeling: use of historical series of MODIS land use datasets, and calibration and validation of a hydrological model using exclusively model-derived meteorological data from NASA-LIS. The methodological approach is detailed in the next sections.

3.1 Datasets

Although earlier in this chapter NASA-LIS, MODIS land use, and SRTM topographical datasets were briefly described, here a more detailed description is provided for further illustrating the potential of those datasets for hydrological modeling.

3.1.1 MODIS 12 Q1 Land use/Landover product

The MODIS Land Cover Type product contains multiple classification schemes, which describe land cover properties derived from observations spanning a year's input of Terra data. The primary land cover scheme identifies 17 land cover classes defined by the International Geosphere Biosphere Programme (IGBP), which includes 11 natural vegetation classes, 3 developed and mosaicked land classes, and three non-vegetated land classes (NASA, 2009).

The NASA MODIS MOD12Q1 Land Cover Product (MODIS/Terra Land Cover, 1000 m spatial resolution) is provided by NASA through several internet portals. The MODIS/Terra Land Cover Type Yearly L3 Global 1km SIN Grid product, MOD12Q1, identifies five classes of land cover (NASA, 2002): Land Cover Type 1 is the IGBP global vegetation classification scheme, the University of Maryland modification of the IGBP scheme (UMD, Land Cover Type 2), the MODIS LAI/fPAR (Land Cover Type 3) scheme, the MODIS Net Primary Production (Land Cover Type 4) scheme, and the Plant Functional Types (PFT) (Land Cover Type 5) provided in consideration of the Community Land Model (CLM) used in climate modeling (NASA, 2005). Land Cover Type 1 IGBP global vegetation classification scheme was used in this study. The dataset was reclassified and re-projected to suit the needs of the HSPF hydrological model.

3.1.2 SRTM topographical dataset

The NASA Shuttle Radar Topography Mission produced the most complete, highest resolution digital elevation model of the Earth. The project was a joint endeavor of NASA, the National Geospatial-Intelligence Agency, and the German and Italian Space Agencies, and flew in February 2000. It used dual radar antennas to acquire interferometric radar data, processed to digital topographic data at 1 arc-sec resolution (Rodriguez et al., 2005). Subsequently, the collected dataset was used by the Jet Propulsion Laboratory (JPL) to generate a near-global topography data product for latitudes smaller than 60 degrees (NASA, 2006). The DEM is provided in geographic coordinates (DTED format) with elevation values referred to WGS84 (horizontally and vertically), meaning that ellipsoidal heights are provided, with Height Error Map (HEM) co-registered to the DEM describing the accuracy of each pixel based mainly on the coherence (Rodriguez et al., 2005). The information contained in this dataset was also geo-processed before input to the HSPF hydrological.

3.1.3 NASA-LIS

The Land Information System (LIS) (Kumar et al., 2006; Peters-Lidard et al., 2007) is a land surface modeling and data assimilation system developed at NASA Goddard Space Flight Center (GSFC) that integrates the use of land surface models, high resolution satellite and observational data, data assimilation techniques and high performance computing tools. LIS operates primarily on an ensemble of land surface models over user-specified regional and global domains. The LIS software is designed using object oriented design principles so that a variety of typical land modeling and assimilation functions are abstracted to function in an interoperable manner. A key new functionality in LIS is the support for sequential data assimilation extensions, enabling the interoperable use of multiple observational sources, land surface models, and data assimilation algorithms (Kumar et al., 2008).

In this research, potential evapo-transpiration and precipitation geographically- distributed time series from NASA-LIS were introduced to the SWAT hydrological model.

3.2 The models HSPF and SWAT

3.2.1 HSPF

For the creation of a HSPF application four files are needed to load topographical, channel geometry and land use information into the HSPF's User Control Input (*.uci) file. Those files are:

- Watershed file (*.wsd): contains sub-basin area and slope (Area Factor and SLSUR in HSPF, respectively)
- Reach file (*.rch): contains information for each stream reach such as elevation difference between start and end of the reach, flags identifying and connecting reaches, etc.
- Channel geometry file (*.ptf): contains information on the stream channel reach geometry (cross sections, length and depth, channel slope, side-slopes) and Manning's roughness coefficient for impervious zones. Used by HSPF to build F-tables for each sub-basin.
- Point sources file (*.psr): point sources discharges in the watershed.

HSPF loads selected information from the files described above into specific tables of the User Control Input file (UCI). The table PWAT-PARM2 from the UCI file uses the slope values from the *.wsd file (per sub-basin) and assigns them to the variable SLSUR. Table RCHRES_HYDR_PARM2 loads the reach length values assigning them to the variable LEN. This table also uses the values of elevation difference between start and end of the reach (variable assigned: DELTH). The assignment of values and variables is shown in Figure 7 having the GIS program BASINS as example, but the scheme is valid for any other GIS system.

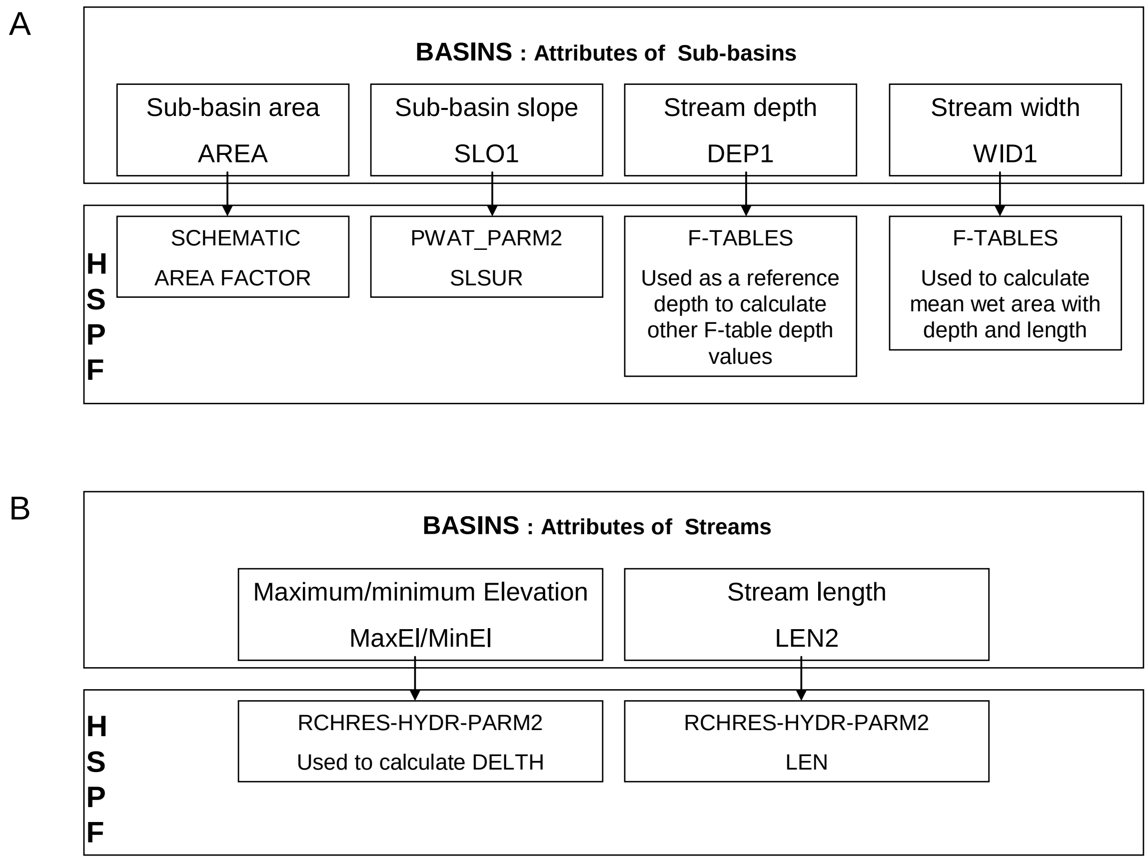


Figure 7. Data transfer from BASINS tables to HSPF tables. Topographical information is transferred from BASINS to HSPF in 6 variables: A) sub-basin area, sub-basin slope, stream depth, stream width, max/min elevation, and, B) stream length (all the information transferred is per sub-basin) (adapted from Alarcon et al., 2006).

The hydrologic routing algorithm in HSPF calculates storages and outflows using rating curves. These function-tables (F-tables) are set-up automatically by HSPF with trapezoidal cross-sections (by default) when a new project is generated from BASINS. The user can modify the cross-sections with other data if available. If the F-tables are not modified by the user, F-tables in the *.uci file are built using the information contained by the *.ptf file. However, although the *.ptf file provides several columns with geometrical attributes of the stream reach, only three columns come directly from the BASINS' summary tables: length of stream, mean width and mean depth. Figure 7 shows a summary of the HSPF use of topographic information extracted from BASINS or from any other GIS program.

Topographical data are used to calculate runoff and hydraulic behavior in streams. HSPF calculates runoff based on the Chezy-Manning equation. The overland flow algorithm uses the sub-basin slope SLSUR variable. The AREA FACTOR values are used to specify areas of a land segments that are tributary to a stream reach. The F-TABLEs specify the geometric and hydraulic properties of a stream reach. Every stream reach is associated with one FTABLE.

DELTH is the drop in water elevation from the upstream to the downstream extremities of the stream reach.

In addition to topographical and land use parameterized information, HSPF also requires hourly precipitation and evapo-transpiration time-series for simulating hydrology. These two forcings can be assigned to each of the sub-basins and reaches independently, allowing great flexibility for calibration and validation of HSPF applications.

3.2.2 SWAT

SWAT is a physically based model. It requires specific information about weather, land use, soil properties, and topography present in the watershed under study. The meteorological variables required by SWAT are: daily precipitation, maximum/minimum air temperature, solar radiation, wind speed and relative humidity. These basic data can be input from records of observed data or generated during the simulation using an embedded weather generator from average monthly values. The model generates a set of weather data for each sub-basin in the watershed. The ability of SWAT to reproduce observed stream hydrographs is greatly improved by the use of measured precipitation data. Unfortunately, even with the use of measured precipitation the model user can expect some error due to inaccuracy in precipitation data. Measurement of precipitation at individual gages is subject to error from a number of causes and additional error is introduced when regional precipitation is estimated from point values. Point measurements of precipitation generally capture only a fraction of the true precipitation.

Evapo-transpiration is a collective term for all processes by which water in the liquid or solid phase at or near the earth's surface becomes atmospheric water vapor. Evapo-transpiration includes evaporation from rivers and lakes, bare soil, and vegetative surfaces; evaporation from within the leaves of plants (transpiration); and sublimation from ice and snow surfaces. Potential evapo-transpiration is the rate at which evapo-transpiration would occur from a large area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water. This rate is assumed to be unaffected by micro-climatic processes such as advection or heat-storage effects. SWAT offers three options (through the weather generator) for estimating potential evapo-transpiration.

SWAT also offers the option for introducing time-series of measured potential evapo-transpiration. However, the program allows only one record of evapo-transpiration for the whole watershed.

2.3 Methodological approach

The approach in this study was to perform a comprehensive comparison of the impacts of using different datasets in HSPF and SWAT hydrological models within a common experimental unit (same geographic and temporal range) and using different combinations of input datasets. Figure 8 illustrates how the different components of the study were assembled.

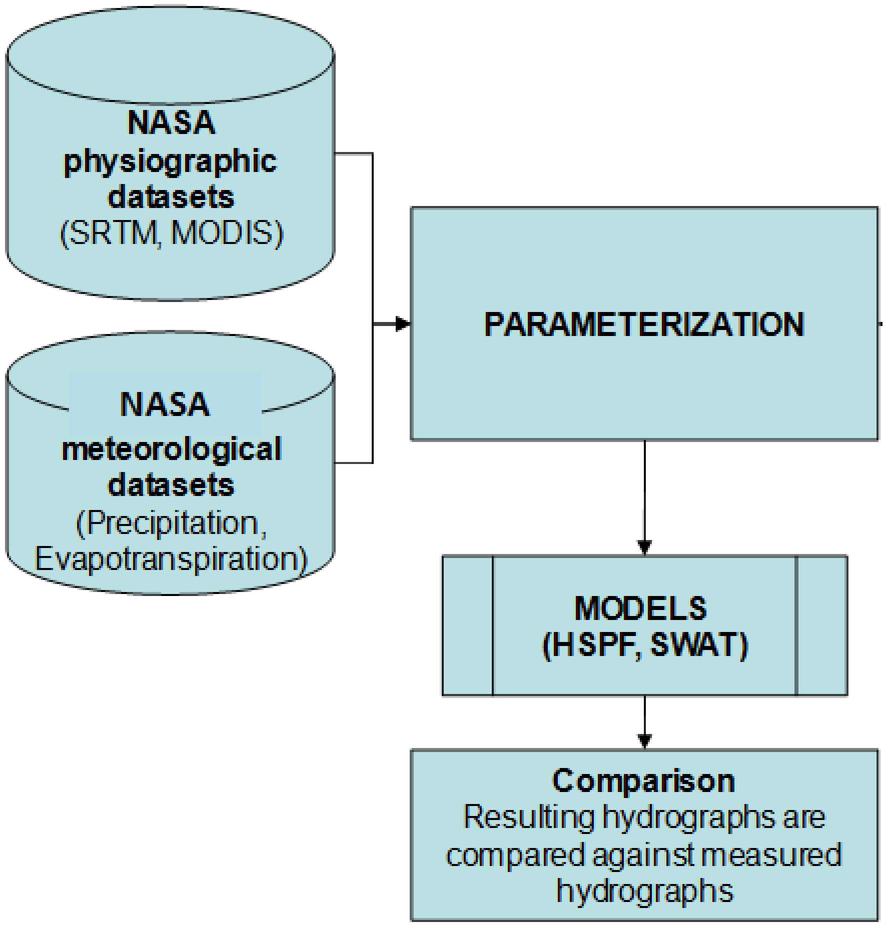


Figure 8. Methodological approach. Absent from this figure is the compulsory hydrological calibration for baseline model applications which provided benchmarks for comparison.

Precipitation gages and USGS gage stations in the region were used to calibrate and validate the HSPF and SWAT base-case model applications. Land use and topographical datasets were swapped to assess model output sensitivities. NASA-LIS meteorological data were introduced in the calibrated model applications for simulation of watershed hydrology for a period in which no weather data were available (1997-2006). The performance of those NASA meteorological datasets was assessed through comparison of measured and model-simulated hydrographs.

2.4 Study Area

The Wolf River catchment, located in Saint Louis Bay watershed (Mississippi Gulf Coast) was the focus of this study (Figure 5). The Wolf River flows into the Mississippi Gulf Coast (St. Louis Bay watershed). The catchment drains slightly more than 98350 ha with an average stream flow of 20.1 m^3/s.

3 Results

3.4 Land use change

MODIS 12Q1 land use products from 2001 up to 2004 were parameterized and introduced in a calibrated HSPF model application for Wolf River watershed. Inexistent precipitation and evapotranspiration time-series were obtained from NASA-GSFC and reformatted to update the original Wolf watershed HSPF application (that runs from 1970 to 1996) up to 2007. Figure 9 shows the MODIS 12Q1 datasets for the years included in this experiment.

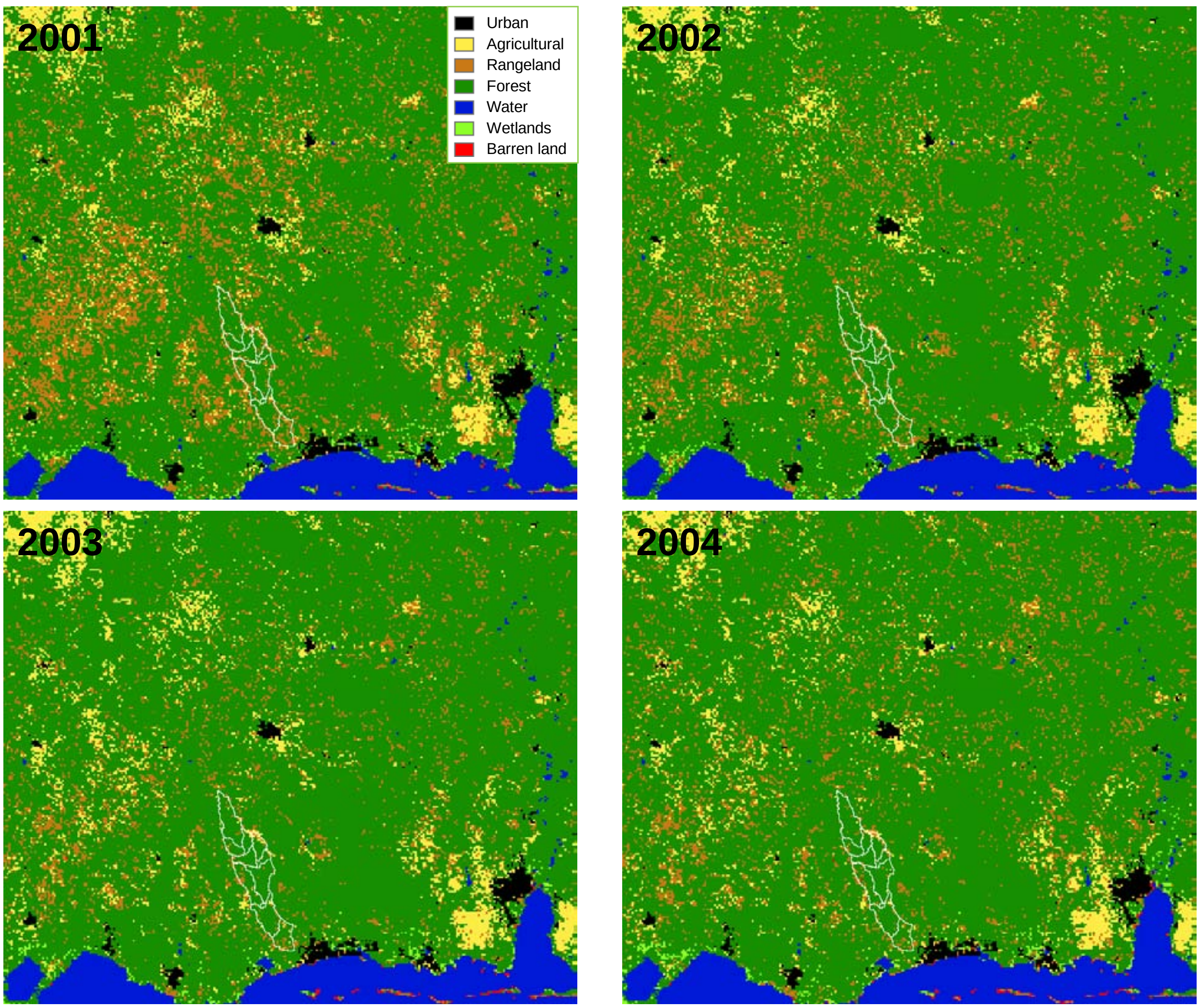


Figure 9. Historical MODIS 12Q1 land use datasets (2001-2004) for the Mississippi Gulf coast. Wolf River watershed is shown in white.

The introduction of yearly land use information to an existing HSPF application generated four different HSPF models for the Wolf River watershed. Ideally, the land use change captured by the MODIS datasets should have been introduced automatically whenever each new year of simulation begun. In HSPF, however, this is not possible. HSPF uses one characterization of land use for the whole simulation period. Introducing land use maps varying in time would require a re-calibration of the model, invalidating any comparison. That is why, each of the models was run from 1997 to 2006 using only one land use map: 2001, 2002, 2003, and 2004, respectively. In this way, this experiment intended to find out if using different MODIS land use maps affected the hydrological estimations of stream flow, as well as indirectly assessing the robustness of NASA-LIS data (precipitation and potential evapo-transpiration) for generating a valid HSPF hydrological model for the Wolf River catchment.

Simulated daily hydrographs at the outlet (Landon Station, see Figure 5) were compared against measured hydrographs at the same outlet (USGS gage station 02481510, also shown in Figure 5). Model fit efficiencies were evaluated for each combination of HSPF model for Wolf and land use map.

Figure 10 shows resulting hydrographs for models using 2001 and 2004 land use MODIS datasets (for brevity, output for years 2002 and 2003 are not shown). Figure 9 also shows the measured hydrograph (from USGS gage station 02481510). As illustrated in the figure, hydrographs have only minor differences. Scatter-plots of observed vs. simulated daily stream flow rates are also very similar. The correlation for the 2001 and 2004 models are R= 0.843 and R=0.845 respectively (corresponding to a common R^2=0.71 value). Therefore, for the period of simulation, the combination of MODIS 12Q1 land use datasets and NASA-LIS precipitation and potential evapo-transpiration datasets generates equivalent HSPF models, i.e., using either MODIS dataset (2001, 2002, 2003, or 2003) does not affect the estimation of stream flow. Also, the use of model derived precipitation and potential evapo-transpiration (from NASA-LIS) was successful since it generated stream flow hydrographs that correlated with measured data.

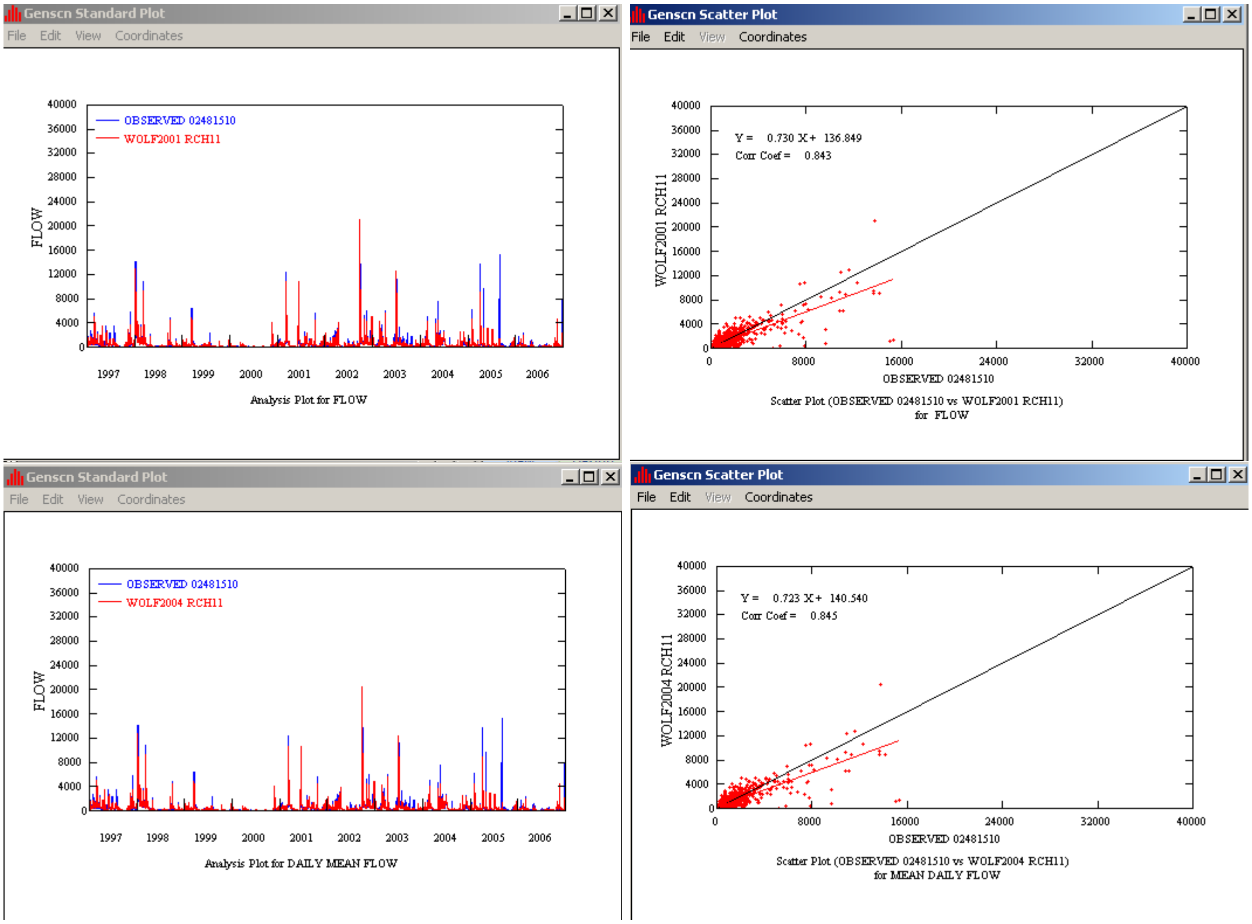


Figure 10. Output hydrographs and scatter–plots for Wolf River Watershed HSPF models using land use datasets MODIS 2001 and MODIS 2004, and NASA-LIS generated precipitation and potential evapo-transpiration (period of simulation 1997-2006).

3.5 Forcings experiment

Although the land use dynamics experiment incorporated NASA-LIS forcings (precipitation and evapo-transpiration) in calibrated HSPF models, the models were previously calibrated and validated with measured gage station data from USGS and NCDC. Therefore, the validity of using NASA-LIS data for generating (independently) a calibrated watershed model was not assessed. In this experiment, that validity is assessed by introducing NASA-LIS precipitation and potential evapo-transpiration data into a SWAT model application for the Wolf River watershed. Figure 11 shows the initial set-up of the SWAT model application for Wolf River Watershed made through the BASINS tool. The NASA-LIS' NLDAS grid and geographical locations of forcing datasets are also shown.

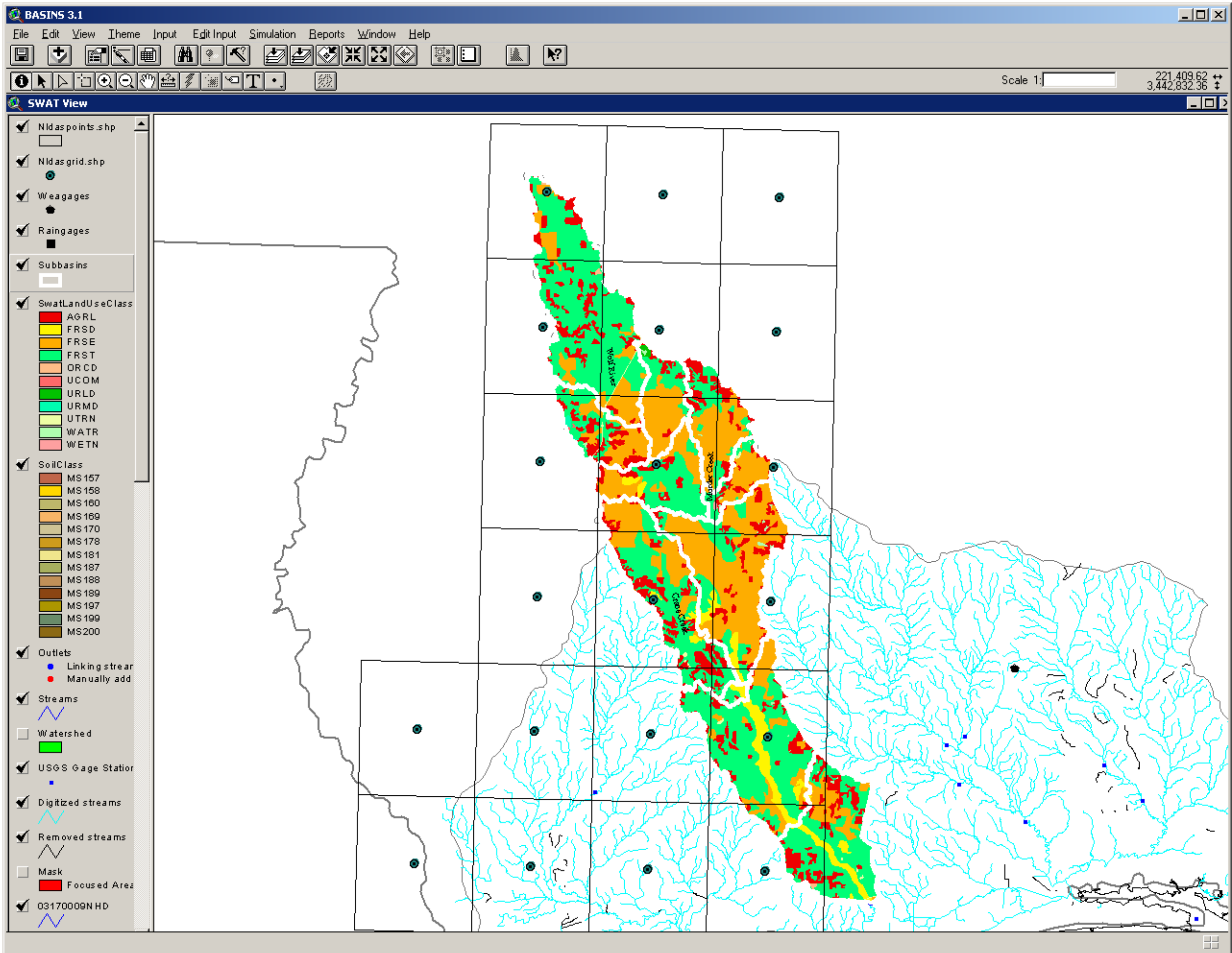


Figure 11. Swat model application for Wolf River Watershed. The NLDAS grid is also shown.

The strategy for introducing NASA-LIS forcings data into the Wolf River watershed SWAT model application followed two paths: a) generating *.DBF input files for operating the SWAT model through the BASINS ArcView interface, and, b) generating *.txt files and operating the SWAT model out of the BASINS interface (DOS console). Both strategies worked equivalently. This experiment was also successful in using the GenScen post-processor for visualization and analysis of the SWAT model output.

The calibration and validation of the SWAT model application for Wolf River watershed was no different from other hydrological models. Figure 12 shows results of this process.

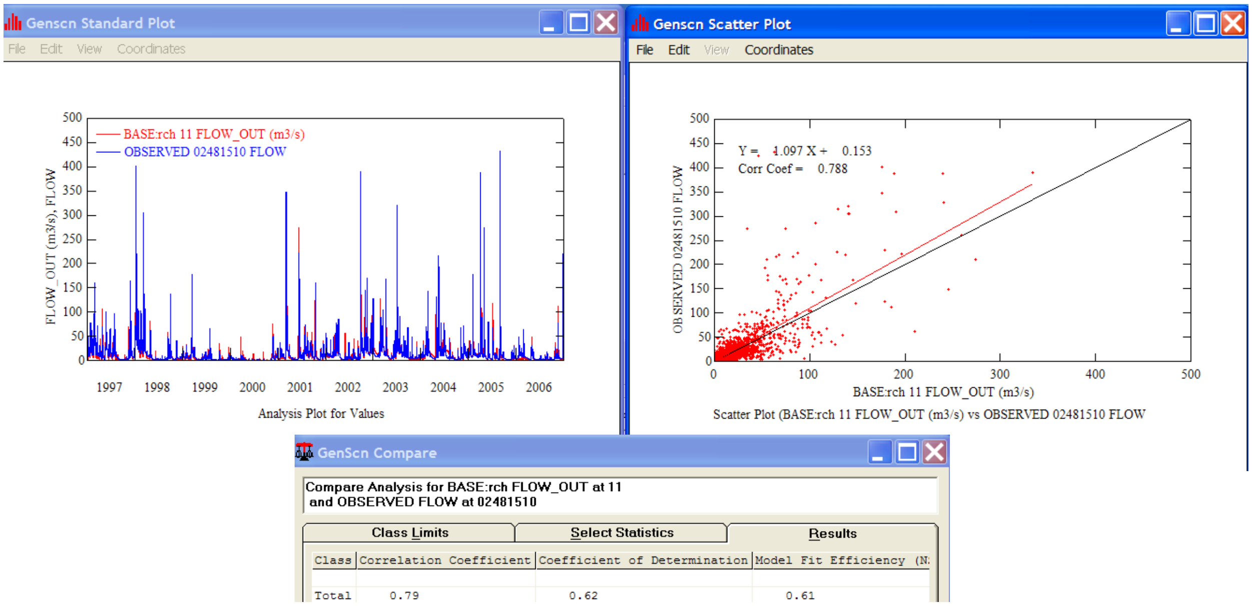


Figure 12. Calibration of the SWAT model application to Wolf River watershed.

As shown in Figure 12, the calibration and validation of the SWAT application to Wolf River Watershed is equivalent to the calibration of a watershed model for the same location using HSPF. A correlation coefficient of 0.79, a coefficient of determination R^2=0.62 and a model fit efficiency of NS= 0.61 were achieved. This shows the validity of using NASA-LIS precipitation and potential evapo-transpiration data for generating a fully calibrated watershed model without requiring gage station data.

5. Conclusions and Recommendations

The conclusions are organized per test-case to provide the reader a consolidated account of the outcomes of this study.

Topography experiment: SRTM, NED and USGS-DEM produce equivalent, smooth and continuous demarcation of sub-basins. Therefore, the topography experiment determined that the use of SRTM provides equivalent delineation results and topographical parameterized information for input in hydrological models.

Land use experiment: The comparison of land use datasets characterization (MODIS MOD 12Q1, GIRAS, and NLCD) of Luxapallila watershed showed that despite small differences in land use acreages (that can be explained by chronological differences in land use information acquisition, spatial resolution of the datasets and processing algorithms) overall the three datasets provided comparable land use characterization of forests (predominant in the area), with some differences in the characterization of agricultural areas. After swapping land use datasets, the HSPF model estimations did not show substantial changes on the water balance components (evapo-transpiration, total runoff, and deep groundwater) and stream flow. Comparisons of simulated annual sediment rates showed noticeable differences attributable to the different capture of agricultural areas by the different land use datasets. This experiment showed the usefulness of MODIS 12Q1 for providing insight in the modeling of flow and sediments in an inland watershed using HSPF.

Combined land use and topography experiment: The combination of moderate resolution topographical datasets (such as SRTM, 30 m) and low resolution land use datasets (such as MODIS, 1000 m) produce good statistical fit between HSPF-simulated and measured stream flow hydrographs. Model fit coefficient for the MODIS-SRTM combination range between 0.73 and 0.81 (perfect fit is 1.00). Therefore, MODIS 12Q1 and SRTM datasets can be used successfully for calibration and validation of coastal watersheds such as Wolf and Jourdan rivers catchments.

Land use change experiment: the combination of MODIS 12Q1 land use datasets and NASA-LIS precipitation and potential evapo-transpiration datasets generates equivalent HSPF models for Wolf River watershed. Using either MODIS dataset (2001, 2002, 2003, or 2003) did not affect the estimation of stream flow. Also, the use of model-derived precipitation and potential evapo-transpiration (from NASA-LIS) was successful, since it generated stream flow hydrographs that correlated with measured data (r^2=0.71).

Forcings experiment: the calibration and validation of the SWAT application to Wolf River watershed, exclusively using NASA-LIS precipitation and potential evapotranspiration, was shown to be equivalent to the calibration of a watershed model for the same location using HSPF. A correlation coefficient of 0.79, a coefficient of determination r^2=0.62 and a model fit efficiency of NS= 0.61 were achieved. This shows the validity of using NASA-LIS precipitation and potential evapo-transpiration data for generating a fully calibrated SWAT watershed model without requiring gage station data.

The only limitation identified in these experiments would be the spatial resolution of the MODIS 12Q1 dataset (1000 m) for short-span hydrological simulation. However, when long periods of hydrological simulation are required, the land use information contained by MODIS MOD 12Q1 seems to be equivalent to finer datasets.

Summarizing, the NASA datasets used in this study were as useful as standard physiographic datasets used by the watershed hydrology modeling community.

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